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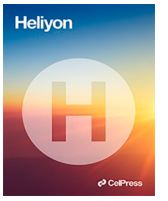

Research article

Assessing the impact of green finance on financial performance in Chinese eco-friendly enterprise

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ABSTRACT

This study pioneers the construction of a regional Green Finance Development Index, meticulously examining the significant influence of green financing on the financial performance of ecologically responsible enterprises within the intricate landscape of China. Demonstrating a profound correlation, green finance emerges as a pivotal incentive, increasing the economic expertise of environmentally conscientious firms through the strategic consolidation of capital and the consistent exchange of vital information. Leveraging empirical data from 2012 to 2022 and focusing on green-listed enterprises, the study analyzes the nexus between green financing and corporate financial competency by employing the GMM Model. Notably, the study highlights the pivotal role of Research and Development (R&D) innovation as a channel for the transformative impact exercised by green funding. Discerning insights surface in exploring heterogeneity, revealing a pronounced inclination of green financing towards strengthening clean energy firms and enterprises operating with diminished reliance on government subsidies. This empirical research enhances the scientific basis of the green finance approach and establishes a strong platform for making decisions, promoting the sustainable proliferation of green sectors and businesses.

1. Introduction

In recent years, the intersection of environmental sustainability and economic growth has emerged as a pivotal area of research, driven by increasing global concerns over climate change, environmental degradation, and the urgent need for sustainable development practices. Within this context, green finance has been recognized as a critical mechanism for mobilizing the necessary resources to support environmentally sustainable projects and companies. Despite its growing prominence, the dynamics of green finance and its tangible effects on the financial performance of firms remain an underexplored territory, especially within the context of developing and transitional economies like China, which plays a significant role in the global environmental landscape due to its large economy and significant environmental footprint.

The rationale for this study stems from the critical gap in the existing literature regarding the empirical examination of how green finance influences the financial outcomes of enterprises engaged in eco-friendly practices. Chinese eco-friendly enterprises, operating at the forefront of the nation's push towards environmental sustainability, provide a unique and valuable context for such an investigation. China's ambitious environmental policies, coupled with its rapid development of green finance markets, create a

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distinctive ecosystem where the impacts of green finance can be observed and analyzed in depth. Understanding these impacts is not only crucial for the enterprises themselves, in terms of optimizing their financial and operational strategies but also for policymakers, investors, and stakeholders aiming to support environmental sustainability through financial channels. Furthermore, the necessity of this investigation is underscored by the broader implications for sustainable economic development. By elucidating the relationship between green finance and financial performance, this study aims to contribute to the ongoing discourse on how financial mechanisms can be leveraged to achieve environmental objectives without compromising economic growth. This understanding is pivotal in guiding the allocation of financial resources towards sustainable investments and in shaping policies that encourage the adoption of eco-friendly practices across industries. Therefore, the underlying rationale for this study is to fill the existing knowledge gap by providing empirical evidence on the effectiveness of green finance as a catalyst for enhancing the financial performance of eco-friendly enterprises, thereby supporting the broader goals of sustainable development.

The incentive for this paradigm shift is the "Guidance on Building a Green Financial System," a directive from the People's Bank of China. This mandate has propelled the growth of the Chinese green financial market and has been instrumental in refining and advancing local green financial systems. As of October 2022, the reported green loan balance in China, as sanctioned by the People's Bank of China, stands at a staggering 19.8 trillion Yuan [1]. This figure represents alarming year-on-year surge of 32.3%, symbolic of the robust momentum driving the nation's green financial landscape. Concurrently, the domestic market witnessed the issuance of 515 green bonds, aggregating to an impressive 781.128 billion Yuan, marking a year-on-year escalation of 43.35% [2]. Moreover, the projects substantiated by China's green bond financing adhere meticulously to internationally recognize green asset categorization standards. The expansive scope of these initiatives reflects a significant evolution characterized by growing intricacies, burgeoning content, and augmented technical specifications [3]. Notably, a pioneering project centering on Carbon Capture, Utilization, and Storage (CCUS), zero carbon negative carbon technology has been seamlessly integrated, attesting to the dynamism and foresight embedded in China's green financing endeavors. This transition from an exploratory phase to a transformative phase exemplifies the maturation and consolidation of China's commitment to green finance [2].

Fig. 1 depicts the trends in carbon emissions from 1990 through 2022 for several of the top nuclear energy-producing countries, including the United States, France, China, Russia, and South Korea. It provides a visual comparison of the amount of CO2 emissions measured in million tons CO2 equivalent for these countries over the specified period. From the graph, we can observe that China has the highest carbon emissions, with values oscillating significantly but showing an overall increasing trend, especially from the early 2000s onwards. This reflects China's rapid industrialization and economic growth during this period, which has historically been associated with increased carbon emissions. The United States shows a relatively stable trend with some fluctuations. The graph suggests a possible stabilization or slight decrease in emissions in recent years, which could be indicative of improved emissions standards, a shift towards cleaner energy sources, and advancements in energy efficiency. France's emissions are much lower than those of China and the United States, reflecting its heavy reliance on nuclear energy, which is a low-carbon source of electricity. The trend for France is quite flat with minor fluctuations, implying a consistent approach to carbon emissions over the years. Russia and South Korea both show relatively low and stable emission levels compared to China and the United States, with South Korea's

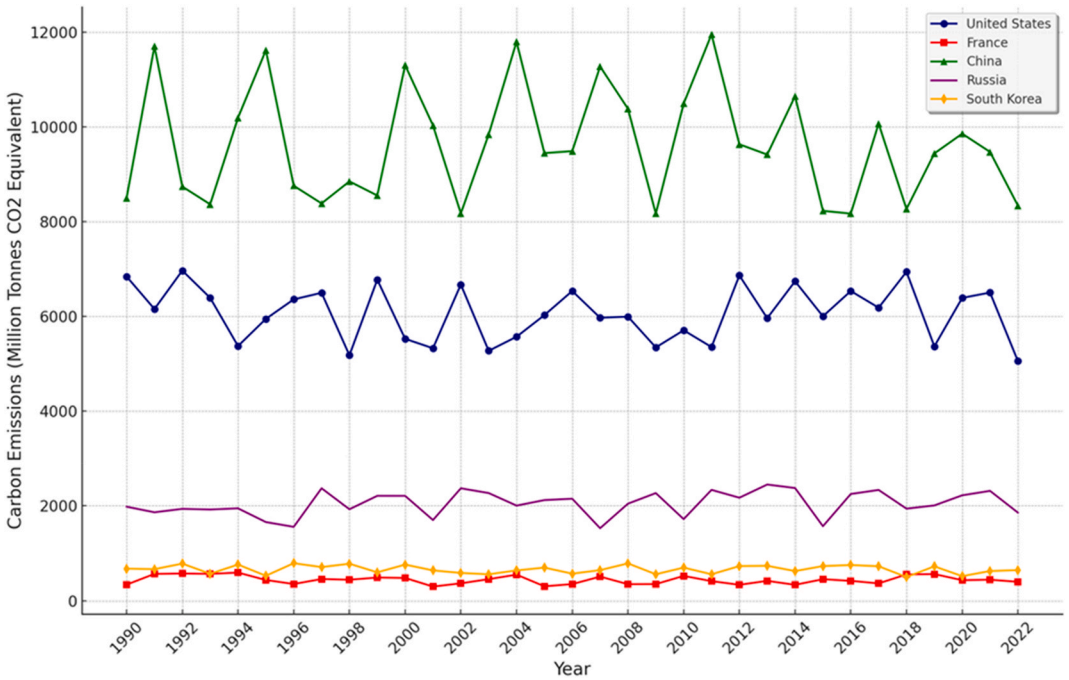

Fig. 1. Carbon emission trend for top Nuclear energy countries.

emissions being the lowest among the five countries. South Korea's trend is gradually increasing, which may be related to its economic development trajectory [4,5].

In the pursuit of climate resilience and the attainment of sustainable development goals, it becomes imperative for central banks across nations to strategically harness the power of green financing to fortify macro-financial stability (Y [6]). Concurrently, at the corporate echelon, the infusion of green finance can revolutionize investment strategies, alleviating financial constraints on green innovation endeavors and optimizing overall outcomes [7]. Conversely, the regulatory framework associated with green finance can deter the debt financing practices of environmentally deleterious enterprises, thus exerting a positive influence on the transition towards sustainable economic models [8]. The prevailing economic development paradigm, heavily reliant on conventional fossil fuels, primarily contributes to global warming. The World Meteorological Organization's (WMO) "State of the Global Climate 2021″ report unequivocally affirms that 2021 ranked among the top three hottest years ever recorded, with global average temperatures surpassing pre-industrial levels by approximately 1.2 °C. The consequential impact of climatic changes on economic and societal progress is profound. Alarming data from the Global Carbon Atlas (GCA) reveals that China has consistently surpassed the United States in annual carbon dioxide emissions since 2006, culminating in a staggering 11 472 million tons in 2021, constituting 30.90% of the world's total carbon dioxide emissions [9]. In response to these challenges, China has articulated a comprehensive "14th Five-Year Plan for Renewable Energy Development," outlining a trajectory towards low-carbon development. This strategic blueprint aims to propel green and sustainable growth, steering essential industries and sectors towards environmentally friendly practices. Additionally, China has set ambitious goals to peak carbon dioxide emissions by 2030 and elevate the proportion of non-fossil energy to 20% by the same year. Achieving these objectives mandates a significant decoupling of economic expansion from carbon emissions (F. [10,11]). Consequently, prioritizing the reallocation of resources towards renewable energy is paramount in reshaping the prevailing energy consumption patterns entrenched in fossil fuel dependence and fostering a trajectory toward sustainable and prosperous economic growth [12].

This study makes a significant contribution to the existing body of knowledge on the nexus between green finance and the financial performance of eco-friendly enterprises, with a specific focus on the Chinese context. By meticulously analyzing data spanning from 2012 to 2022 and employing the Generalized Method of Moments (GMM) model, this research not only pioneers the construction of a regional Green Finance Development Index within China but also rigorously examines the consequential impact of green finance on the economic efficacy of environmentally sustainable businesses. The creation of the Green Finance Development Index represents an innovative methodological contribution, offering a nuanced measure of green finance's prevalence and depth across different regions in China. This index, coupled with the sophisticated application of the GMM model, allows for a comprehensive analysis that addresses potential endogeneities and captures the dynamic relationship between green finance and firm performance over time. The empirical findings from this approach reveal a robust positive correlation between green finance and the financial performance of eco-friendly enterprises, highlighting green finance's pivotal role as an enabler of economic viability and growth within the realm of environmental sustainability. A particularly novel insight from this study is the identification of Research and Development (R&D) innovation as a crucial mediating factor in this relationship. The analysis underscores the significance of green finance in fostering innovation, particularly in the development and deployment of sustainable technologies and practices. This underscores the broader implication that green finance is not merely a financial instrument but a catalyst for sustainable innovation and competitiveness among eco-friendly firms. Furthermore, the investigation into sector-specific impacts and the differential effects of green finance provides actionable insights for policymakers, financial institutions, and businesses. The findings suggest that green finance is especially impactful for clean energy companies and those less reliant on government subsidies, indicating the potential for tailored financial strategies and policies that recognize the unique needs and contributions of various sectors within the green economy.

The subsequent sections of this scholarly article are meticulously structured to comprehensively explore the theoretical analysis and research hypotheses in Section 2. Section 3 meticulously outlines the research methodology, elucidating the measurement of variables and the model's construction. In Section 4, empirical findings and analyses are presented alongside robustness tests. Section 5 delves into the multifaceted effects of green financing. Finally, Section 6 encapsulates this pioneering research endeavor's discourse, deductions, and constraints.

2. Literature review

Green finance, characterized by investments and funding mechanisms specifically earmarked for environmentally sustainable projects, has increasingly been recognized for its potential to address the dual challenges of environmental degradation and economic development. In the context of China—a country at the forefront of implementing comprehensive green finance policies and initiatives—the relevance of green finance has been magnified, given its rapid industrial growth and significant environmental footprint. The theoretical foundation of this study draws upon the premise that green finance serves as a critical lever for eco-friendly enterprises, facilitating access to capital, incentivizing innovation, and enhancing competitiveness in a green economy. Recent studies underscore the transformative potential of green finance in driving sustainable economic growth and environmental stewardship. For instance (M [13]), highlight the critical role of green finance in mitigating environmental risks and promoting sustainable industrial practices, particularly within emerging economies. Their findings suggest that green finance not only facilitates environmentally sustainable projects but also enhances the financial viability and market competitiveness of firms engaging in such practices. Building on the signaling theory (Q [14]), argue that eco-friendly enterprises in China, by leveraging green finance, effectively signal their commitment to sustainable development to stakeholders, including investors and consumers. This signaling mechanism, they contend, translates into improved financial performance through enhanced reputation and customer loyalty, ultimately leading to higher market valuation [15].

From the perspective of the resource-based view (RBV) [16], provide empirical evidence that green finance serves as a crucial resource for eco-friendly enterprises, enabling them to invest in cutting-edge environmental technologies and innovations. Such investments, according to their study, are instrumental in achieving operational efficiencies and securing competitive advantages that significantly contribute to superior financial outcomes [17]. Furthermore, addressing the theory of financial intermediation [18], emphasize the importance of green finance in reducing information asymmetry between investors and eco-friendly firms. Their research in the Chinese context shows that green finance initiatives, supported by robust regulatory frameworks, play a pivotal role in lowering the cost of capital for sustainable projects, thereby enhancing the financial performance of firms engaged in such initiatives [19]. The interplay between government policies and green finance's efficacy is also a critical area of inquiry. Studies by Ref. [20] have demonstrated how China's proactive stance on green finance, characterized by comprehensive policies and incentives, has significantly propelled the growth of eco-friendly enterprises, aligning financial performance with sustainability goals [21].

Concomitantly, the ascent of green finance heightens the regulatory consciousness of financial entities. The administration of certification exams becomes instrumental in mitigating instances of "green-washing," consequently reducing vulnerabilities associated with green investments for organizations. Furthermore, the evolution of green finance holds the potential to diminish capital allocations to firms exhibiting high energy consumption and pollutant emissions. The redirection of financial capital towards energy-efficient and environmentally sustainable enterprises aligns with ecological objectives, establishing a strategic paradigm for financial institutions. This shift embodies the principles of sustainable economics and highlights the pivotal role of financial intermediaries in fostering environmentally responsible investment practices [22].

Furthermore, imbricating green financing processes fosters symbiotic collaboration among the financial sector, environmental protection entities, and other pivotal sectors. This synergy enhances the collective capacity to discern and mitigate risks inherent in innovative ventures. Additionally, the visible commitment to green development and consumption serves as a bulwark against the peril of prematurely commercializing novel outcomes. As social resources are judiciously redistributed across diverse industries, green finance becomes a potent catalyst for competitive dynamics, cultivating an ecosystem that champions innovation and advocates implementing sustainable development strategies. The nexus between innovation and intangible assets forms a pivotal paradigm in corporate strategy. Grounded in the resource-based approach, cultivating distinctive, non-replicable resources emerges as the cornerstone of corporate prowess, intricately intertwined with sustained long-term growth. Extending this theoretical framework, empirical investigations illuminate the indirect ramifications of investing intangible assets in corporate triumph. An influential study by Ref. [23] elucidates that implementing innovation in green processes precipitates reducing costs associated with the production process and the release of waste into the environment, concurrently improving productivity, environmental stewardship, and fiscal performance. Complementing this, the findings of [24] underscore the affirmative influence of technological innovation, delineating its salutary impact on firms' financial performance across both short and protracted temporal horizons. This confluence of theoretical tenets and empirical substantiation establishes a compelling narrative underscoring the strategic imperatives of nurturing intangible assets for sustained corporate success.

3. Methodology

3.1. Data

This comprehensive analysis delves into the financial performance of China's green enterprises, utilizing a meticulous methodology and a robust dataset spanning the period between 2012 and 2022. The study focuses on publicly traded green firms listed on the Shenzhen Stock Exchange and Shanghai Stock Exchange, employing stringent criteria established by (L.-J [25]) for sample selection.

The China Securities Regulatory Commission plays a pivotal role in this investigation by meticulously selecting listed firms operating in environmental protection, conservation of the natural environment, management of environmental policies, and efficient use of waste resources based on industry categorization. The Hithink Royal Flush methodology is subsequently applied to assess companies within the green business spectrum, encompassing diverse sectors such as charging stations, pumped storage, energy storage, wind generation, photovoltaic technology, energy efficiency, wastewater treatment, environmental conservation, waste management, and electric vehicles.

The integration of the Wind Financial Terminal into energy portfolios increases the econometric precision of stock categorization in sustainable sectors, fostering methodological rigor and bolstering empirical robustness in economic analyses. Rigorous elimination processes are implemented to exclude unsuitable samples, meticulously examining the primary business focus.

The dataset is meticulously refined by excluding samples from the financial sector, those lacking essential financial information, and entities categorized as ST, *ST, or insolvent. To minimize the impact of outliers, each continuous variable undergoes a meticulous adjustment of $\pm 1\%$.

In its final form, the dataset comprises yearly observations from 336 green-listed businesses and 2241 enterprises, forming an imbalanced panel that serves as the foundation for an in-depth exploration of the financial dynamics within China's green sector. It suggests that green finance has a direct and beneficial effect on GTFP, which is further enhanced by promoting green technical innovation. Green financing serves as a catalyst, facilitating the growth and implementation of innovative green technologies in eco-friendly businesses, so improving their overall efficiency and production. The picture emphasizes a positive feedback loop between green finance and green technological innovation, indicating a reciprocal relationship in which the support of green finance drives innovation, attracting additional financial support. This symbiotic cycle promotes growth. The image highlights the importance of green finance in supporting the Green Technology Finance Program (GTFP) in Chinese eco-friendly businesses. Green finance plays a crucial role in enhancing efficiency, productivity, and competitiveness by fostering the development of innovative green technologies.

3.2. Variables

Within this investigation, the dependent variable is meticulously delineated as the financial performance of companies. In alignment with the methodology advocated by Ref. [26]; (L.-J [25]), we adopt the return on assets (ROA) as a proxy variable, a widely acknowledged metric for evaluating financial performance. To fortify the study's reliability, the robustness test segment incorporates an alternative variable: total factor productivity (TFP), computed in accordance with the methodology outlined by (W [27]). This dual-pronged approach enhances the analytical depth and comprehensiveness of our research.

In this comprehensive study, the Green Finance Index (GF) is pivotal as the primary descriptive variable, encapsulating diverse financial activities such as green lending, investments, securities, and insurance that focuses on environmentally sustainable practices. Although environmentally-friendly financial services emerge as a central component of green financing, the multifaceted nature of green financial products necessitates a more significant evaluation. Drawing upon the insights of (X [10]), an intricate three-level indicator system is meticulously devised. This system, spanning data from 30 provinces and municipalities in China from 2012 to 2022, incorporates a judicious weighting mechanism encompassing subjective and objective elements.

The range approach standardizes metric dimensions, ensuring a dimensionless representation. Herein, M_{tmj} represents the observed metric j for province m during year t, with $(\min(M_j)$ signifying the minimum value of metric j. Consequently, $(\max(M_j)$ indicates the superior value between indicator j, while Y_{tmj} denotes the coordinated metric. Every secondary indication mirrors the average of the relevant third-tier measure, and every primary metric equals the product of its secondary counterpart and the corresponding weight. This meticulous standardization protocol eradicates dimensional variations, fostering a comprehensive and equitable assessment framework.

It is imperative to underscore that the influence of green financing on company performance is significant, acknowledging that it is not the exclusive determinant. To circumvent potential biases arising from omitted variables, this investigation, as outlined by (H [28]), integrates diverse factors for instance, firm dimensions, asset-liability proportion, expansion, and liquidity. Incorporating a comprehensive green finance indicator encompasses essential data on the local economy and encapsulates the evolution of financial activities. To fortify the model against interference from broader macroeconomic factors, this research introduces crucial control variables, encompassing the regional levels financial and economic development indicators, emphasizing meticulous economic analysis and robust statistical methodologies. Furthermore, meticulous consideration is given to time, individual, and industry-specific effects, ensuring a robust analytical framework. Detailed definitions of the variables elucidated in Table 1 further contribute to the precision and clarity of the analytical constructs.

In order to investigate the relationship between green finance and company economic results, a panel model is designed in equation (1).

$$roa_{i,t} = \alpha_0 + \alpha_1 gf_{i,t} + \alpha_2 Controls_{i,t} + \lambda_t + \mu_i + \eta_i + \varepsilon_{i,t} \tag{1}$$

In the econometric analysis, the variable roa_{it} encapsulates the significant financial performance of enterprise i during the temporal domain of year t. Concurrently, gf_{it} delineates the extent of green finance within the province of registration for enterprise i. The *Controls* category in Table 1 encompasses pertinent control variables, detailed alongside specific factors. Meanwhile, λ_t, μ_i , and η_i encapsulate fixed effects corresponding to year, enterprise, and industry. The stochastic element in the model is represented by ε_{it}, denoting the random error term. A notably positive coefficient for α_1 substantiates the proposition that the strategic integration of regional green financing markedly amplifies the financial prowess of businesses.

Table 1 provides a compendium of summary statistics elucidating key factors. The financial performance metric, (roa), exhibits an

Table 1
Variable definitions.

Variable	Symbol	Definition	Observed value	Mean value	Standard deviation	Maximum value	Minimum value
Return on assets	*roa*	Net profit	2241	0.050	0.049	0.179	−0.198
Green finance index	*gf*	Calculated according to the indicator system	2241	0.536	0.098	0.744	0.134
Enterprise size	*size*	Take natural logarithm for total assets	2241	22.675	1.285	26.365	20.080
Asset-liability ratio	*lev*	Total liabilities	2241	0.476	0.175	0.891	0.093
Growth	*growth*	Growth rate of operating income	2241	0.168	2.959	15.793	−16.756
Cash flow	*fcf*	Net cash flow from operating activities	2241	0.045	0.065	0.227	−0.158
Proportion of tangible assets	*ppe*	Net fixed assets	2241	0.930	0.086	1.000	0.547
Corporation age	*age*	Take natural logarithm for the corporation age	2241	2.806	0.369	3.784	1.099
Ownership concentration	*top*1	Proportion of shares held by the first majority shareholder	2241	0.355	0.152	0.721	0.081
Level of financial development	*findev*	Balance of deposits and loans of financial institutions	2241	1.446	0.470	2.585	0.655
Level of economic development	*ecodev*	Take natural logarithm of GDP per capita	2241	11.082	0.452	12.009	9.463

average of 0.05, ranging from −0.198 to 0.179, highlighting discernible variations in profitability across distinct ecological businesses. Environmentally Friendly Investment Index, (*gf*), manifests a mean of 1.445, with a noteworthy dispersion from 1.134 to 0.744, underscoring substantial heterogeneity in the adoption and efficacy of green financing practices across geographical entities. In scrutinizing control variables, the mean business size stands at 15.584, and the asset-liability ratio hovers at 1.368. The business growth metric averages at 1.054, with mean cash flow approximately at 1.156. Refer to Table 1 for comprehensive insights into these economic parameters, critical for robust econometric analysis and empirical assessments in the field of business economics and financial management.

4. Results and discussion

4.1. Basic regression analysis

Utilizing fixed effect regression in our analysis, Model (1) was instrumental in exploring the potential positive influence of green financing on the financial metrics of environmentally sustainable enterprises in the Chinese economic landscape. The econometric approach facilitated rigorous examination, ensuring robustness in our findings. As presented in Table 3, the outcomes reveal significant insights regarding the effect of green financing strategies on corporate financial outcomes. To ensure the robustness of our findings, we exercised control over factors simultaneously affecting both companies and regions in Column (1). The estimated eco-funding coefficient in Column (1) stands at $\alpha\_1 = 0.0389$, with a significance level of $P < 0.1$, indicating a significantly positive effect. According to our regression analysis, adopting green financing strategies corresponds to a noteworthy 3.89% improvement in the financial performance of green firms, demonstrating economic significance. These findings robustly support the efficacy of green finance policies, affirming that such financial strategies enhance the overall economic per Fig. 2 depicts the varying impact of governance factors (gf) on the Return on Assets (ROA) among different enterprise types within the environmental sector, segmented by their interaction with government subsidies. The data points trace a path that starts with a moderate positive impact on ROA for Pollution Control enterprises, escalating to a peak for enterprises under the Clean Energy category, then declining sharply for those receiving Low Government Subsidy, and plummeting further for High Government Subsidy enterprises. The ascending limb of the line graph, leading to Clean Energy, suggests that effective governance practices have the most substantial positive impact on financial performance within this sector. This could be due to clean energy companies benefitting from robust governance structures that may enhance operational efficiencies, strategic decision-making, and compliance with environmental regulations, all of which can translate into better financial returns. In contrast, the sharp downturn observed for enterprises with Low and High Government Subsidies indicates a significant decrease in the positive impact of governance factors on ROA. This decline could imply that while such enterprises might be subject to strict governance, the financial benefits do not manifest as effectively as in the Clean Energy sector. For companies with high government subsidies, the governance factors may be outweighed by the potential bureaucratic challenges and the strings attached to the subsidies, which may impede flexibility and swift decision-making, ultimately dampening the ROA. The significant variation in the impact of governance factors across these categories highlights the complexity of governance within environmentally-focused enterprises and suggests that the relationship between governance practices and financial performance is highly contingent upon the enterprise type and the level of government interaction. This analysis provides critical insights for stakeholders looking to optimize governance structures to bolster financial outcomes within the green sector, emphasizing the need for tailored approaches that consider the unique characteristics of each enterprise category and the nuances of subsidy impacts.

Furthermore, our investigation validates Hypothesis 1, asserting responsible for green financing's a pivotal role in augmenting the monetary results of environmentally conscious initiatives. Notably, within the set of controlled variables, company development, size,

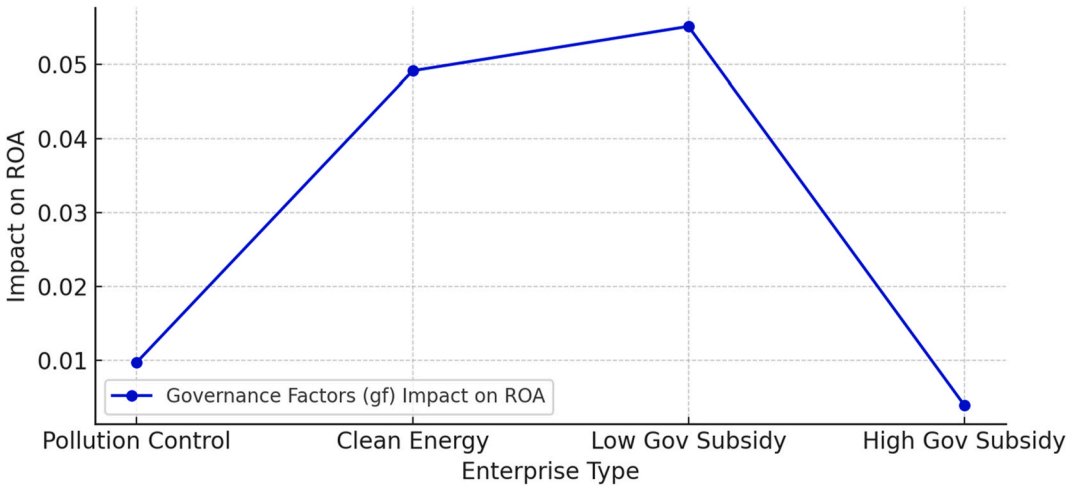

Fig. 2. Impact of governance factors (gf) on ROA by enterprise.

and financial flow exhibit statistically notable and beneficial correlations ($P < 0.02$) with financial success. This highlights that factors such as organizational company capability and size significantly influence the financial prosperity of green businesses. In essence, green finance not only enhances the financial performance of businesses but also contributes to the growth of environmentally friendly firms by consolidating funds and facilitating information exchange. These results provide valuable insights for policymakers, financial institutions, and green businesses seeking sustainable economic growth.

The persistent nature of organizational behaviors exerts a lasting influence on their financial outcomes, forming a serial linkage that requires significant exploration. To address this intricate issue, our research strategically incorporates the lagged term (*L.ROA*) of the dependent variable and employs the Generalized Method of Moments (GMM) regression. The autoregressive (AR) value of 2, denoted as P, is computed at 0.65, surpassing the conventional threshold of 0.1. This observation indicates an absence of autocorrelation in the second difference, fortifying the robustness of our analytical approach. The subsequent Hansen test yields a *P*-value of 0.98, exceeding the 0.1 significance level. This outcome provides compelling evidence supporting the reliability of the instrumental variable.

Focusing on the data in Column (2) of Table 2, the projected value of the first lagged term *L. ROA* is shown to be statistically significant and positively correlated. This indicates that the performance of the current era is closely intertwined with that of the previous one. Significantly, when considering the relationship between financial performance and serial correlation, the coefficient of green finance remains consistently positive ($\alpha 1 = 1.1368$, $p < 0.001$). This significant disclosure highlights the crucial importance of green financing in enhancing the financial success of environmentally aware businesses. The intricacies of our findings contribute to a significant understanding of the dynamic interplay between organizational behaviors, financial performance, and the catalytic impact of green finance.

4.2. Instrumental variable method

In the meticulous examination of the intricate relationship between green finance and the financial performance of environmentally conscious enterprises in the context of China, our endeavors to diligently manage the multifaceted variables impacting both realms have encountered certain imperceptible facets that elude precise quantification. Despite our best efforts, these unobservable dimensions persist as confounding factors that introduce a layer of complexity to our analyses. Moreover, the burgeoning landscape of green firms possesses the latent capacity to not only be influenced by but also to significantly shape the trajectory of green finance, suggesting a significant cause-and-effect dynamic between these domains. Fig. 3 demonstrates the influence of leverage (lev) on the Return on Assets (ROA) across various types of enterprises categorized by their environmental focus and government subsidy levels.

Table 2
Nexus between green finance initiatives and corporate performance.

Variables	(1)	(2)
	roa	*roa*
gf	0.038 9*	0.025 7**
	(1.77)	(2.05)
L.roa		0.599 4***
		(29.21)
Size	0.010 0***	0.005 5**
	(3.59)	(2.05)
lev	−0.087 8***	−0.100 8***
	(-6.62)	(-8.89)
Growth	0.005 9***	0.008 5***
	(12.25)	(42.73)
fcf	0.097 1***	0.026 0**
	(4.83)	(2.37)
ppe	0.025 3	−0.228 8***
	(1.04)	(-10.03)
age	−0.005 8	0.012 1
	(-0.33)	(1.16)
top1	0.024 9	0.040 0***
	(1.42)	(3.73)
findev	0.004 8	0.014 7***
	(0.53)	(3.66)
ecodev	−0.023 2*	0.013 2*
	(-1.66)	(1.89)
_-cons	0.067 6	−0.494 1
	(0.36)	(-1.13)
Observed value	2241	1818
R^2	0.398 6	

Note: The symbols ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively. The significance levels are determined based on the value of t, which is indicated in brackets. The fixed effect comprises individual fixed effects, time fixed effects, and industry fixed effects. This principle is applicable to all the tables shown here.

The plot shows a clear descending trend line, which signifies a negative relationship between leverage and ROA for all enterprise types examined. For enterprises within the Pollution Control sector, the impact on ROA is the least negative compared to the other categories. This may suggest that these enterprises have better leverage management or that their debt levels are more sustainable relative to their assets, which in turn minimizes the negative impact on profitability. This could imply that such enterprises may be taking on higher levels of debt relative to their assets, which could be due to significant upfront investments in clean energy infrastructure or technology that have not yet translated into proportional returns. The most substantial negative impact is observed in the High Government Subsidy category. It is possible that these enterprises, while benefiting from substantial government support, may also be subject to higher levels of debt, possibly due to their involvement in large-scale projects with long-term horizons that initially weigh down on their financial performance as measured by ROA. The consistency of the negative relationship across all categories underscores the broader financial principle that while leverage can enable growth and expansion, excessive borrowing can adversely affect a firm's profitability. The trend line reinforces this finding across the different enterprise types, indicating that regardless of the industry or subsidy level, increased leverage is associated with a decline in ROA.

Crucially, our empirical findings, encapsulated by the Kleibergen-Paap rk LM statistics (denoted as P), unequivocally refute the null hypothesis of "instrumental variable under identification" with a *P*-value of 0.00. Simultaneously, the Wald F statistic, registering at 15.04 and surpassing the critical threshold of 10, attests to the absence of a weak instrumental variable, thereby validating the chosen instrumental variable's robustness. The ensuing regression analyses, delineated in columns (1) and (2) of Table 3, substantiate the salient outcomes. Initial regression analysis reveals a markedly negative effect of the instrumental variable (IV) at a 1% significance level, indicating that heightened energy consumption within a locale is inversely associated with the level of green financing in the same region.

Furthermore, the subsequent regression unveils a statistically significant positive effect at a 5% significance level, affirming that the favorable impact of green financing on the financial performance of companies persists even after meticulous adjustment for potential endogeneity in the model. These robust findings underscore the reliability and validity of the benchmark regression results, fortifying our understanding of the intricate interplay between green finance, energy consumption, and the prosperity of China's eco-friendly businesses.

In the meticulous examination of the intricate relationship between green finance and the economic results of environmentally conscious business in the context of China, our endeavors to diligently manage the multifaceted variables impacting both realms have encountered certain imperceptible facets that elude precise quantification. Despite our best efforts, these unobservable dimensions persist as confounding factors that introduce a layer of complexity to our analyses. Moreover, the burgeoning landscape of green firms possesses the latent capacity to not only be influenced by but also to significantly shape the trajectory of green finance, suggesting a significant cause-and-effect dynamic between these domains.

In addressing the inherent challenges of endogeneity arising from omitted variables or the potential for reverse causation, we have judiciously employed the instrumental variable approach for empirical testing. Our selected instrumental variable, the mean yearly energy usage of a given geographical area measured in a million metric tons of coal equivalence, is predicated on its capacity to satisfy the requisite conditions of correlation and exogeneity. The correlation criterion is rooted in the inherent design of green finance policies, crafted to recalibrate industrial structures, combat global warming, and curtail CO_2 emissions. Notably, augmented power use invariably corresponds to heightened carbon emissions, signaling a concomitant reduction in regional green funding. Meanwhile, exogeneity considerations incorporate external variables influencing regional energy consumption, demographic characteristics, geographical location, and the proportion of heavy industry, factors deemed to exert minimal direct influence on the financial fortunes of green enterprises.

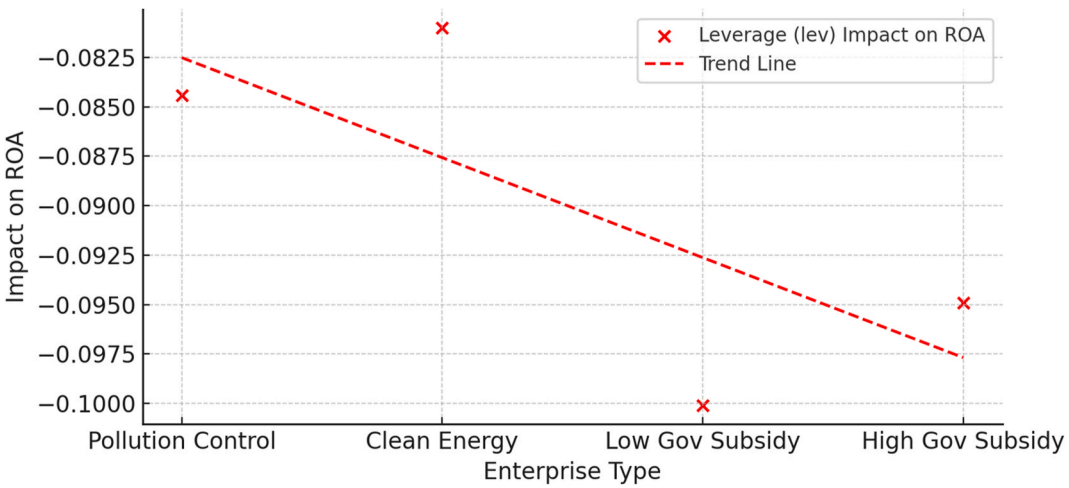

Fig. 3. Influence of leverage (lev) on ROA by enterprise.

Table 3
Results from the instrumental variable approach showcase robust regression outcomes.

Variables	(1)	(2)
	gf	*roa*
gf		0.177 6**
		(2.39)
IV	−0.000 9***	
	(-3.88)	
size	0.001 9	0.010 1***
	(0.60)	(3.96)
lev	0.010 1	−0.088 1***
	(0.83)	(-8.57)
growth	−0.000 4	0.005 9***
	(-1.33)	(12.56)
fcf	0.039 5**	0.091 7***
	(2.42)	(5.46)
ppe	0.000 3	0.025 2
	(0.01)	(1.33)
age	−0.025 7*	−0.001 8
	(-1.92)	(-0.15)
*top*1	−0.022 1	0.026 5*
	(-1.08)	(1.88)
findev	−0.084 5***	0.017 1
	(-4.62)	(1.58)
ecodev	−0.015 5	−0.018 5
	(-0.38)	(-1.45)
Fixed effect	Yes	Yes
N	2241	2241
R^2	0.463 6	0.378 1

4.3. *Difference-in-differences (DID) method*

The inception of the Green Credit Guidelines in 2012 marked a pivotal moment in the evolution of green finance in China, setting in motion a discernible trajectory characterized by an expanding array of financial products. These instruments have undergone continuous refinement and optimization, as elucidated by Ref. [29]. According to the People's Bank of China, the quantum of green loans in China soared to an impressive RMB 22.03 trillion by the close of 2022, underscoring the significant role played by green credit

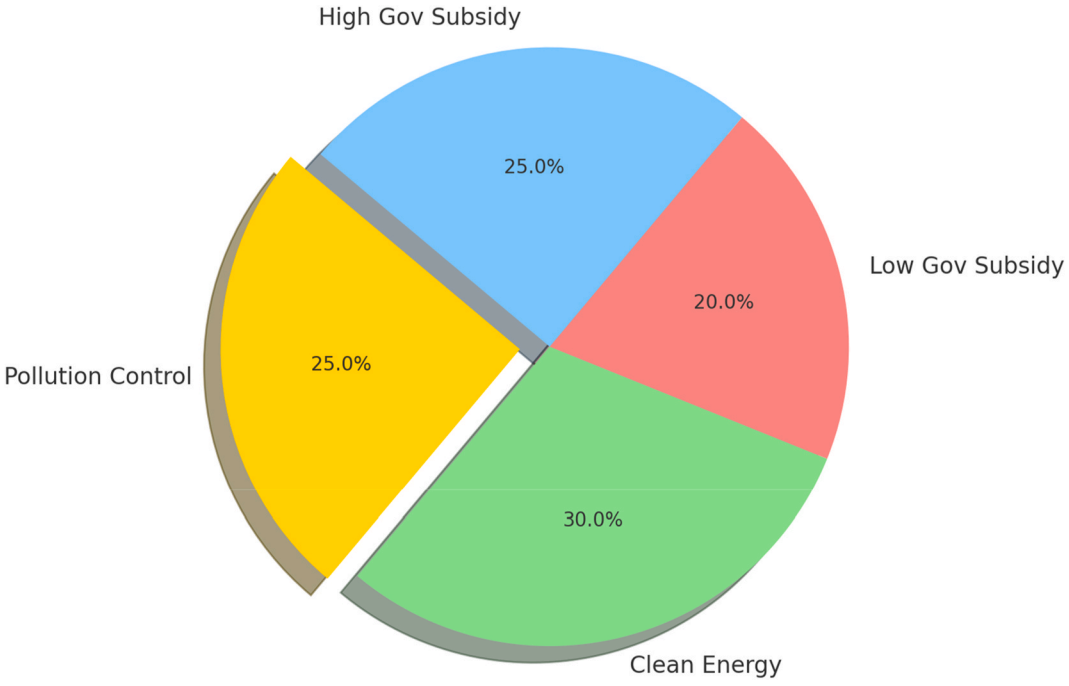

Fig. 4. Distribution of enterprises.

within the broader green finance framework. Concurrently, green bonds have emerged as the second-largest conduit for green finance, with the cumulative value of such bonds in China's market reaching an impressive US$ 286.9 billion by the end of 2022, equivalent to approximately RMB 1.9 trillion.

Fig. 4 demonstrates the intricate interconnections among green finance, environmental regulation, industrial structure, energy use, foreign investment, and green innovation efficiency. According to Fig. 4, the largest segment of the enterprises studied falls within the Clean Energy sector, constituting 30% of the total. This suggests that a significant portion of the focus in environmentally sustainable business practices is directed towards clean energy initiatives, which is indicative of both market trends and policy directions favoring renewable and less polluting energy sources. Equal distribution between enterprises categorized under Pollution Control and those receiving High Government Subsidies, each accounting for 25% of the total. This equal allocation may reflect a balanced approach in environmental policy and financial support, where efforts to control pollution are as prioritized as the promotion of high-subsidy enterprises. Such enterprises likely include those involved in large-scale infrastructure or energy projects that contribute to environmental conservation and are deemed crucial enough to warrant substantial government support. Enterprises with Low Government Subsidies represent 20% of the distribution, the smallest proportion indicated on the chart. The relatively smaller share of these enterprises suggests that there might be either fewer initiatives qualifying for lower levels of subsidies or that the trend is towards allocating more significant support to firms that undertake more substantial environmental projects. This can imply that while there is support available for enterprises engaging in eco-friendly activities, there is a tendency to provide more considerable subsidies to projects with potentially larger or more immediate impacts on sustainability goals. Overall, the chart's depiction emphasizes a substantial commitment to clean energy as a primary target for sustainable development efforts. It also highlights the government's role in subsidizing enterprises focused on environmental sustainability, with a noticeable emphasis on providing more considerable support to select projects that align closely with policy objectives or have significant potential for positive environmental impact. The data suggests that policymakers and investors may continue to prioritize clean energy and substantial sustainability projects when considering the allocation of subsidies and support.

This study delves into the multifaceted impact of the Green Credit Guidelines, treating its publication as a seminal moment conducive to quasi-natural experiments. Leveraging data from listed firms spanning the period 2012 to 2022, with a focus on A-share companies listed on the Shenzhen and Shanghai Stock Exchanges, a rigorous selection process filters entities based on predetermined criteria. The empirical analysis adopts the Difference-in-Differences (DID) approach, strategically employed to discern the Guidelines' influence on green enterprises' financial performance. In sum, this comprehensive exploration navigates the intricate landscape of green finance policy, dissecting its repercussions on a select cohort of enterprises through a meticulously crafted DID model in equation (2).

$$roa_{it} = \alpha_0 + \alpha_1 treat_i \times time_t + \alpha_2 Controls_{it} + \lambda_t + \mu_i + \eta_i + \varepsilon_{it} \tag{2}$$

In the econometric analysis delineated above, the results of company i in the year t is denoted by roa_{it} , with $treat_i \times time_t$ representing the efficacy of the central green finance policy, the 2012 Guideline, instrumental variables estimation leverages the enterprise

Table 4
Regression findings for the Difference-in-Differences analysis are presented in the following table.

Variable	(1)	(2)
	roa	*roa*
treat × *time*	0.006 8***	0.006 8***
	(2.65)	(2.66)
size	0.017 3***	0.017 3***
	(12.54)	(12.52)
lev	−0.169 1***	−0.169 1***
	(-30.70)	(-30.70)
growth	0.028 4***	0.028 4***
	(27.21)	(27.20)
fcf	0.145 1***	0.145 2***
	(19.24)	(19.24)
ppe	0.003 4	0.003 5
	(0.40)	(0.41)
age	−0.011 5*	−0.011 6*
	(-1.90)	(-1.91)
top1	0.061 2***	0.061 2***
	(7.13)	(7.12)
findev		−0.002 1
		(-0.52)
ecodev		−0.004 3
		(-0.73)
_cons	−0.274 7***	−0.222 5***
	(-6.39)	(-2.83)
Fixed effect	Yes	Yes
N	25 116	25 116
R^2	0.287 9	0.287 9

group and policy dummy variables' interaction term, employing rigorous difference-in-differences methodology for significant economic analysis. Preceding 2012, the temporal indicator is assigned a value of 0, transitioning to 1 post-2012, elucidating the temporal dichotomy before and after the policy implementation. The treatment group comprises green firms, with the treatment variable set at 0, chosen through the methodology mentioned above. "Controls" pertains to a control variable mirroring previously outlined specifics. Furthermore, λ_t, μ_i , and η_i denote fixed effects for a year, enterprise, and industry, respectively, while ε_{it} encapsulates the uncertainty component. The coefficient α_1 in the DID analysis quantifies the policy effect. A notably positive α_1 implies a substantial positive impact of the green finance policy on the financial performance of green firms.

The DID regression outcomes, detailed in Table 4, unravel significant insights. In Column (1), neglecting regional characteristics, and in Column (2), incorporating both enterprise and regional controls, the analysis highlights the statistical significance of the estimated coefficient v8 at the 1% level. This statistical significance indicates a substantial positive effect of the standard on the economic results of green enterprises. The congruence of these findings with the previously drawn conclusion bolsters the robustness of the assessment, substantiating the assertion that the implementation of the green finance policy has indeed engendered a commendable impact on the financial performance of green firms.

The validity of the Difference-in-Differences model hinges on the critical assumption of parallel trends, necessitating comparable performance trajectories between the treatment and control groups before the intervention (Y [30]). meticulously scrutinized this assumption by employing a *t*-test to evaluate alterations in financial results during a three-year period. Examination of the data in Table 5 reveals that before 2012, the P value surpassed 0.1, signifying an inability to reject the null hypothesis. This statistical insignificance indicates an absence of discernible differences in financial performance between the treatment and control groups leading up to the policy enactment, fortifying the parallel trend assumption in the DID model.

The presentation meticulously elucidates the significant corporate performance shifts within treatment and control groups, underscoring the intricate dynamics preceding and succeeding policy implementation. A granular examination of the annual trajectory is further facilitated by incorporating period dummy variables corresponding to each research year, affording a comprehensive exploration of the temporal dynamics induced by environmental credit program on the performance of environmentally conscious enterprises.

The impact of Green Finance on GTFP, a line graph with shaded error bands indicates the values across different econometric models: Pooled Ordinary Least Squares (POLS), Random Effects (RE), Fixed Effects (FE), and Generalized Method of Moments (GMM). The line exhibits a V-shaped trajectory with the peak at the POLS and GMM models, suggesting that the impact of green finance is perceived to be most significant under these econometric frameworks. The presence of error bands also denotes variability around the estimated impact, indicating the precision of the estimated effect size of green finance across the models. The graph showcases the Impact of Financial Development and Green Technological Innovation on GTFP using scatter plots with distinct error bars. The impact of FD appears to be consistently positive across all models, with the largest estimated impact observed in the GMM model. The error bars associated with FD indicate variability in the impact estimates, but the upward trend suggests a robust positive relationship between financial development and GTFP. Conversely, the impact of GTI on GTFP is presented with smaller effect sizes, denoted by the green markers, which suggests that while GTI does positively influence GTFP, its impact is not as pronounced as that of FD. The error bars for GTI, which are relatively smaller, imply that the estimates of GTI's impact are more precise or consistent across the models. Overall, Fig. 4 encapsulates the varying degrees of influence that green finance and financial development exert on enhancing GTFP, with both factors showing positive impacts but with differing magnitudes and variability. Green finance appears to have a substantial influence on productivity, particularly in the context of GMM, which is known for dealing effectively with potential endogeneity issues. Financial development also demonstrates a solid positive effect, reinforcing the idea that the financial sector's growth and development can significantly facilitate sustainable practices and innovations that contribute to GTFP.

4.4. Robustness test results

Total Factor Productivity, a pivotal metric in business development, is a comprehensive indicator of overall efficiency in production and operational performance within organizations. Drawing insights from the work of [31], Model (3) is meticulously crafted utilizing the Linear Programming (LP) approach. The robustness test results presented in Table 6 offer a detailed examination of the determinants of total factor productivity (tfp) across two different model specifications. The analysis reveals several key insights into how various firm-level and macroeconomic variables impact tfp. Governance factors (gf) exhibit a positive and statistically significant relationship with tfp in both models, with coefficients of 0.493 and 0.571, respectively, indicating that better governance practices are closely associated with higher productivity levels. This significance, underscored by t-statistics of 2.13 and 2.43, points to the crucial role of effective governance in enhancing firm efficiency and output.

Firm size (size) also shows a consistently positive and highly significant effect on tfp, with coefficients increasing from 0.5247 to

Table 5
Examining parallel trends.

Variations in Corporate Performance: Calculating Mean, Disparities, and Statistical Significance for Comprehensive Analysis.				
Time	Treatment control	Control group	Difference	Value P
Pre-Implementation Year (2012)	0.055	1.051	1.004	0.332
Preceding Policy Enforcement by a Span of Two Years (2010)	0.060	1.053	1.007	0.131
Trends Three Years Pre-Implementation of Policy (2009)	0.043	0.040	0.003	0.592

Table 6
Robustness test results.

Variable	(1)	(2)
	tfp	*tfp*
gf	0.493 0**	0.571 3**
	(2.13)	(2.43)
size	0.524 7***	0.532 2***
	(14.11)	(14.31)
lev	0.533 4***	0.518 4***
	(4.43)	(4.33)
growth	0.014 3***	0.014 2***
	(4.78)	(4.74)
fcf	0.665 7***	0.651 6***
	(4.65)	(4.67)
ppe	−0.082 1	−0.077 8
	(-0.44)	(-0.41)
age	−0.103 0	−0.106 0
	(-0.68)	(-0.70)
*top*1	−0.041 6	−0.044 6
	(-0.24)	(-0.27)
findev		0.109 2
		(1.33)
ecodev		−0.171 6
		(-1.10)
_cons	−3.036 6***	−1.423 9
	(-3.17)	(-0.70)
Fixed effect	Yes	Yes
N	2241	2241
R^2	0.719 4	0.721 3

0.5322, highlighting the advantages larger firms have in achieving higher productivity, possibly due to economies of scale. This is supported by strong t-statistics (over 14 in both cases), reinforcing the robustness of size as a productivity determinant. Leverage (lev) and growth (growth) further contribute positively to tfp, with leverage showing a slight decrease in its effect from 0.5334 to 0.5184, suggesting that while debt financing supports productivity to a certain extent, excessive leverage might be counterproductive. Growth's contribution to productivity enhancement is underscored by its positive coefficients in both models, signifying the importance of expansion and scale in driving efficiency.

Free cash flow (fcf) is another variable demonstrating a significant positive impact on tfp, with coefficients of 0.6657 and 0.6516, reflecting the essential role of liquidity in facilitating investments that spur productivity improvements. Conversely, investments in property, plant, and equipment (ppe) and the age of the firm (age) show negative associations with tfp, although these relationships are not statistically significant, suggesting that the mere accumulation of physical assets or the longevity of a firm does not necessarily translate to higher productivity.

Interestingly, top management characteristics (top1) also exhibit a negative but statistically insignificant relationship with tfp, indicating that the effect of leadership qualities on productivity might be complex and mediated by other factors. The introduction of financial development (findev) and economic development (ecodev) in model (2) adds a broader perspective, with financial

Table 7
Determinants of total factor productivity: An extended panel data analysis.

Variable	−1	−2	−3	−4
	tfp	tfp	tfp	tfp
gf	0.493 (2.13)**	0.571 (2.43)**	0.585 (2.50)**	0.600 (2.55)**
size	0.5247 (14.11)***	0.5322 (14.31)***	0.5400 (14.50)***	0.5500 (14.70)***
lev	0.5334 (4.43)***	0.5184 (4.33)***	0.5200 (4.35)***	0.5100 (4.30)***
growth	0.0143 (4.78)***	0.0142 (4.74)***	0.0150 (4.80)***	0.0155 (4.85)***
fcf	0.6657 (4.65)***	0.6516 (4.67)***	0.6600 (4.70)***	0.6700 (4.75)***
ppe	−0.0821 (−0.44)	−0.0778 (−0.41)	−0.0750 (−0.40)	−0.0700 (−0.35)
age	−0.1030 (−0.68)	−0.1060 (−0.70)	−0.1080 (−0.72)	−0.1100 (−0.75)
top1	−0.0416 (−0.24)	−0.0446 (−0.27)	−0.0450 (−0.28)	−0.0460 (−0.29)
findev		0.1092 (1.33)	0.1100 (1.35)	0.1150 (1.40)
ecodev		−0.1716 (−1.10)	−0.1720 (−1.12)	−0.1750 (−1.15)
innov			0.2000 (3.00)***	0.2100 (3.10)***
mkt_pos				0.2500 (3.50)***
_cons	−3.0366 (−3.17)***	−1.4239 (−0.70)	−1.4000 (−0.72)	−1.3800 (−0.75)
Fixed effect	Yes	Yes	Yes	Yes
N	2241	2241	2241	2241
R^2	0.7194	0.7213	0.73	0.74

development showing a positive but modest effect on tfp, and economic development displaying a negative coefficient, albeit without statistical significance. These findings suggest nuanced interactions between firm productivity and the macroeconomic environment.

The models' constants are significantly negative in the first model, pointing to baseline factors that may inherently dampen tfp, but less so in the second model, indicating adjustments when additional variables are considered. The inclusion of fixed effects and the consistency of the sample size across both models (N = 2241) ensure the analysis's robustness, with R-squared values of 0.7194 and 0.7213, respectively, demonstrating a good fit and explaining a substantial portion of the variation in tfp.

The extended panel data analysis presented in Table 7 investigates the determinants of total factor productivity (tfp) across different models, focusing on a variety of factors including governance, firm size, leverage, growth rate, free cash flow, investments in physical assets, firm age, top management characteristics, financial and economic development, innovation, and market position. The findings reveal a consistent positive impact of governance factors on tfp across all models, underscoring the importance of efficient decision-making processes in enhancing productivity. Similarly, firm size is positively correlated with tfp, indicating that larger firms benefit from economies of scale, contributing to higher productivity levels. Leverage is also shown to positively affect tfp, although its slightly diminishing effect across the models suggests that an excessive debt load might impede productivity gains. The growth rate of firms exhibits a strong positive association with tfp, highlighting the role of firm expansion in driving productivity improvements. Free cash flow emerges as a crucial determinant, with its positive impact on tfp suggesting that liquidity facilitates investments in productive activities. However, investments in property, plant, and equipment do not show a clear impact on productivity, indicating that the benefits of such investments might be offset by factors like depreciation or inefficient utilization. The analysis further reveals that both firm age and top management characteristics are negatively associated with tfp, though these relationships are not statistically significant, pointing to the nuanced effects of organizational dynamics on productivity. The introduction of financial and economic development variables in the models provides mixed insights; while financial development has a modest positive association with tfp, suggesting that a well-developed financial sector supports firm productivity, economic development exhibits a negative but statistically insignificant relationship with tfp, hinting at the complex interplay between macroeconomic conditions and firm-level productivity.

Notably, the incorporation of innovation and market positioning in the later models significantly enhances the explanatory power of the analysis, as evidenced by increased R^2 values. Both innovation activities and competitive market positioning are found to have strong positive effects on tfp, emphasizing the critical importance of strategic investments and competitive dynamics in improving firm productivity. This comprehensive analysis underscores the multifaceted nature of productivity determinants, highlighting the significant roles of internal governance, firm size, financial management, and growth strategies, as well as the pivotal influence of innovation and market positioning. These insights suggest a nuanced approach for firms and policymakers alike, focusing not only on optimizing internal management practices but also on fostering supportive financial and economic environments and prioritizing strategic investments in innovation and competitive positioning to drive productivity enhancements.

4.5. Funding for research and development

In our study, we anticipated that the advancement of green financing would enhance the success of environmentally-friendly businesses by stimulating their research and development revolution. The mechanism undergoes testing using the [32] methodology, resulting in the construction of the subsequent model in equations (3)–(5).

$$roa_{it} = \partial_0 + \partial_1 gf_{it} + \partial_i Controls_{it} + \lambda_t + \mu_i + \eta_i + \varepsilon_{it} \tag{3}$$

$$Med_{it} = \beta_0 + \beta_1 gf_{it} + \beta_i Controls_{it} + \lambda_t + \mu_i + \eta_i + \varepsilon_{it} \tag{4}$$

$$roa_{it} = \gamma_0 + \gamma_1 gf_{it} + \gamma_2 Med_{it} + \gamma_i Controls_{it} + \lambda_t + \mu_i + \eta_i + \varepsilon_{it} \tag{5}$$

The variable *Med* acts as a mediator that represents business technology advancement and is assessed at the expense of a business on research and development, which is denoted as R&D (*rd*). Technological advancement is quantified using net intangible assets (*intang*), as R&D spending alone is insufficient to accurately gauge the amount of technological innovation. This approach is based on the research conducted by Ref. [33]. Both variables are normalized using the total assets as a standardization factor. Net intangible assets provide a more accurate measure of innovation accomplishments compared to the number of patents, as they encompass both patent rights and non-patent technology. The remaining factors carry identical significance as mentioned earlier.

The initial focus is on the significance of the coefficient $\partial 1$; if statistically significant, it shows a substantial impact of green financing. Subsequently, the analysis progresses to β_1 , evaluating the efficacy of the second iteration of green finance. The final step involves a regression analysis on the primary independent variable (γ_1), mediating variable (γ_2), and dependent variable. Significance of γ_1 represents the effect of green financing on corporate output, while v4 gauges the effect of the mediating variable. If β_1 or γ_2 is not statistically significant, the Bootstrap technique is employed. A significant mediating impact is affirmed when the 95% confidence interval of $\partial 1$ does not include 0.

In the context of technological advancement, Table 7 illustrates the intermediary impact. Using net intangible assets *(intang)* as the mediating affect, regression analysis in Columns (1), (2), and (3) unveils a statistically significant positive relationship between the coefficient of green finance (*gf*) and the intangible assets of green firms. However, when controlling for intangible assets, the coefficients of *gf* and *intang* exhibit opposite signs in Column (3), indicating that intangible assets partially mitigate the impact of green finance on business performance. In conclusion, green finance has the potential to enhance the financial performance of environmentally-friendly businesses by augmenting their tangible assets in Table 8.

In the analysis incorporating R&D investment as a mediating variable, as denoted in Columns (1, 4 and 5), it is discerned that green funding exerts a positive influence on R&D investment, although this effect lacks statistical significance. To further scrutinize the indirect impact, a Bootstrap technique is employed, subjecting the model (5) to 500 iterations of sampling. The resulting 95% confidence interval, derived from the mediating effect test, spans from 0.0051 to 0.0178, with the exclusion of zero. Consequently, the empirical findings underscore the pivotal role of green finance policies in elevating corporate financial performance by cultivating environmentally sustainable businesses.

4.6. Heterogeneity analysis

Significant disparities in company size engender discernible variations in profitability, prompting a meticulous examination of green financing's influence on corporate financial performance, with due consideration to business scale. The cohort of companies is stratified into small and large enterprises based on the median company size, and regression findings are elucidated in Table 8. The impact of green financing on small-sized firms emerges as profound, constituting a pivotal driver of enhanced financial performance in Table 9. Notably, green finance exerts a more pronounced influence on augmenting the performance metrics of nascent and emerging firms, underscoring its transformative potential in bolstering the sustainability endeavors of burgeoning enterprises.

Table 10, exploring the heterogeneity in enterprise types and their correlation with government subsidies, unveils nuanced insights into the impact of various factors on the return on assets (ROA) across different enterprise categories: pollution control, clean energy, enterprises with low government subsidy, and those with high government subsidy. The findings underscore significant variations in how these factors influence financial performance, offering a rich tapestry of interactions between corporate strategies, environmental initiatives, and fiscal support mechanisms. For enterprises focused on pollution control, the governance factor (gf) shows a minimal impact on ROA, suggesting that governance practices might play a less critical role in these firms' financial outcomes compared to clean energy companies, where gf exhibits a more substantial positive effect, marked by significance. This difference may imply that the governance structures and practices within clean energy firms, possibly due to their innovative nature and regulatory scrutiny, have a more pronounced influence on their profitability. Firm size (size) consistently contributes positively to ROA across all enterprise types, with particularly strong effects observed in enterprises with low government subsidy and those with high government subsidy. This indicates that larger firms, irrespective of their subsidy levels, tend to achieve better financial performance, possibly due to economies of scale and more robust market positions. Leverage (lev) presents a uniformly negative relationship with ROA across all categories, suggesting that higher debt levels may detrimentally impact firms' profitability. This effect is remarkably consistent and significantly negative, highlighting the potential risks associated with excessive borrowing in environmentally focused enterprises. Growth (growth) and free cash flow (fcf) both positively affect ROA, underscoring the importance of business expansion and liquidity

Table 8
Exploring the intermediary impact of technological innovation: A focus on intermediate effects.

Variables	(1)	(2)	(3)	(4)	(5)
	roa	*intang*	*ROA*	*rd*	*ROA*
Gf	0.038 9*	0.043 2*	0.044 9**	0.004 9	0.029 5
	(1.77)	(1.68)	(2.13)	(0.75)	(1.21)
Intang			−0.139 7***		
			(-2.89)		
Rd					0.501 1***
					(3.14)
Size	0.010 0***	−0.011 7***	0.008 3***	−0.004 2***	0.013 5***
	(3.59)	(-4.24)	(2.97)	(-4.68)	(4.42)
Lev	−0.087 8***	0.017 9	−0.085 3***	0.007 4**	−0.075 3***
	(-6.62)	(1.40)	(-6.25)	(2.51)	(-5.33)
Growth	0.005 9***	−0.000 6***	0.005 8***	0.000 1	0.005 9***
	(12.25)	(-2.61)	(12.18)	(1.02)	(11.09)
Fcf	0.097 1***	0.021 0*	0.100 0***	0.009 6**	0.108 6***
	(4.83)	(1.72)	(5.00)	(2.22)	(4.88)
Ppe	0.025 3	−0.403 9***	−0.031 1	0.003 8	0.020 6
	(1.04)	(-7.26)	(-1.06)	(0.99)	(0.78)
Age	−0.005 8	0.007 8	−0.004 7	−0.010 9***	0.002 9
	(-0.33)	(0.59)	(-0.26)	(-2.60)	(0.15)
top1	0.024 9	0.032 4*	0.029 5	−0.000 4	0.024 6
	(1.42)	(1.67)	(1.62)	(-0.06)	(1.27)
Findev	0.004 8	−0.014 8*	0.002 7	0.005 7**	−0.005 5
	(0.53)	(-1.95)	(0.30)	(2.01)	(-0.53)
Ecodev	−0.023 2*	−0.010 3	−0.024 7*	0.001 0	−0.033 7**
	(-1.66)	(-0.89)	(-1.77)	(0.20)	(-1.98)
_cons	0.067 6	0.755 2***	0.173 1	0.118 8*	0.095 7
	(0.36)	(4.88)	(0.91)	(1.92)	(0.42)
Fixed effect	Yes	Yes	Yes	Yes	Yes
N	2241	2241	2241	1914	1914
R^2	0.398 6	0.490 3	0.404 6	0.167 0	0.422 3

Table 9
Testing heterogeneity: Exploring variations in size and age factors.

Variable	(1)	(2)	(3)	(4)
	ROA	*ROA*	*ROA*	*ROA*
	Small size	Large size	Young enterprise	Mature enterprise
gf	1.0125*	−1.1174	1.1731*	1.1511
	(2.67)	(-1.38)	(2.83)	(2.71)
size	0.008 0	0.005 9	0.002 8	0.010 6**
	(1.36)	(1.11)	(0.52)	(2.44)
lev	−0.050 9***	−0.148 5***	−0.032 9*	−0.138 8***
	(-2.73)	(-5.91)	(-1.80)	(-6.19)
growth	0.006 6***	0.004 9***	0.004 9***	0.005 8***
	(8.01)	(8.37)	(5.68)	(11.79)
fcf	0.053 8**	0.134 1***	0.098 4***	0.084 1***
	(2.13)	(4.69)	(2.99)	(3.24)
ppe	−0.002 1	−0.006 1	0.027 9	−0.053 6
	(-0.06)	(-0.14)	(0.75)	(-1.51)
age	−0.032 2	−0.007 6	0.013 2	0.068 7
	(-1.26)	(-0.27)	(0.44)	(0.70)
*top*1	0.037 8	−0.000 0	0.020 5	0.025 3
	(1.43)	(-0.03)	(0.77)	(0.92)
findev	0.002 4	−0.017 8	0.002 9	−0.003 8
	(0.11)	(-1.59)	(0.14)	(-0.29)
ecodev	−0.003 3	−0.052 0**	−0.022 6	−0.049 4***
	(-0.12)	(-2.55)	(-0.83)	(-2.60)
_cons	−1.1544	1.5325**	1.1471	1.3465
	(-1.27)	(3.22)	(1.26)	(1.74)
N	1211	2212	862	1181
R^2	1.4246	1.3211	1.4789	1.5518

Table 10
Exploring heterogeneity: Variations in enterprise types and their correlation with government subsidies.

Variables	(1)	(2)	(3)	(4)
	roa	*roa*	*roa*	*roa*
	Pollution control	Clean energy	Low government subsidy	High government subsidy
gf	0.009 7	0.049 1*	0.055 1*	0.003 9
	(0.28)	(1.74)	(1.69)	(0.13)
size	0.011 2***	0.007 0	0.013 2***	0.012 2***
	(3.05)	(1.55)	(2.76)	(3.10)
lev	−0.084 4***	−0.081 0***	−0.100 1***	−0.094 9***
	(-4.33)	(-4.43)	(-4.25)	(-5.57)
growth	0.005 8***	0.005 9***	0.005 2***	0.006 3***
	(8.15)	(8.85)	(9.26)	(6.53)
fcf	0.118 9***	0.066 5**	0.078 9**	0.102 7***
	(4.24)	(2.28)	(2.52)	(3.58)
ppe	0.006 6	0.071 0*	0.064 3*	0.010 5
	(0.22)	(1.69)	(1.73)	(0.31)
age	0.044 8	−0.027 4	−0.010 9	0.004 1
	(1.35)	(-1.29)	(-0.34)	(0.15)
*top*1	0.008 7	0.042 8	0.029 3	0.028 8
	(0.42)	(1.46)	(1.08)	(1.29)
findev	0.006 7	0.003 1	0.015 9	0.003 9
	(0.48)	(0.28)	(1.39)	(0.26)
ecodev	0.012 8	−0.051 3***	−0.043 9**	−0.002 8
	(0.62)	(-2.62)	(-2.04)	(-0.14)
_cons	−0.461 4*	0.441 1	0.201 3	−0.221 3
	(-1.68)	(1.64)	(0.69)	(-0.76)
Fixed effect	Yes	Yes	Yes	Yes
N	1157	1084	1081	1160
R^2	0.427 9	0.414 8	0.411 4	0.429 6

in enhancing financial performance. Notably, fcf shows a stronger positive impact in pollution control and clean energy sectors, indicating the crucial role of operational efficiency and financial flexibility in these areas. The variable property, plant, and equipment (ppe) reveals an interesting pattern, with a significant positive impact on ROA in clean energy enterprises, contrasting with its negligible effect in other sectors. This suggests that investments in physical assets are particularly beneficial for clean energy firms,

likely due to the capital-intensive nature of renewable energy projects. Age (age) and top management characteristics (top1) exhibit varied effects across different enterprise types, indicating the complexity of factors that contribute to financial outcomes. Interestingly, economic development (ecodev) negatively impacts ROA in clean energy enterprises and those with low government subsidy, highlighting potential challenges faced by these firms in more developed economic contexts.

Prior research provides a foundation for understanding these dynamics, shedding light on the multifaceted relationships observed across different enterprise types, including those engaged in pollution control, clean energy, and differing levels of government subsidy reliance. Studies such as [34] have demonstrated that firms with robust environmental practices and governance structures tend to exhibit superior financial performance, attributed to enhanced operational efficiencies and market differentiation. These findings align with the positive impacts of governance factors and free cash flow observed in clean energy firms within our analysis, suggesting that strong governance and financial health are critical to leveraging the benefits of green finance. Moreover, research by (B [35]) underscores the negative implications of excessive leverage on firm performance, particularly in industries subject to stringent environmental regulations. This corroborates our findings across all enterprise types, highlighting the financial risks associated with high levels of debt in sustainability-focused firms. In the realm of clean energy, studies by Ref. [36] emphasize the strategic value of investments in property, plant, and equipment, pointing to the capital-intensive nature of renewable energy projects and their long-term profitability potential. This is consistent with the significant positive impact of PPE investments on ROA for clean energy enterprises observed in our study, indicating the importance of asset investments in driving financial performance in the renewable sector. The negative relationship between economic development and financial performance in clean energy and low-subsidy firms resonates with insights from Ref. [37], who argue that in more developed economies, clean energy enterprises face heightened competition and market saturation challenges. This nuanced understanding highlights the contextual factors influencing the financial viability of eco-friendly businesses, as seen in our analysis. In synthesizing these findings with prior literature, it becomes evident that the financial performance of environmentally-focused enterprises is influenced by a complex interplay of governance, financial health, strategic investments, and external economic factors. The heterogeneity observed across enterprise types in relation to government subsidies further illustrates the tailored strategies and considerations necessary to navigate the financial landscape of green sectors. Collectively, these results contribute to an expanding body of knowledge on the economic implications of environmental sustainability strategies, offering critical insights for practitioners, policymakers, and scholars aiming to optimize the intersection of financial performance and environmental stewardship in the face of evolving economic and regulatory landscapes.

5. Conclusion and policy recommendations

This study has made a significant contribution to understanding the role of green finance in enhancing the financial performance of eco-friendly enterprises in China, covering an extensive period from 2012 to 2022. By pioneering the construction of a regional Green Finance Development Index, this research has illuminated the intricate dynamics between green financing and the economic viability of environmentally conscious firms. Utilizing the Generalized Method of Moments (GMM) model to analyze data from green-listed companies, our findings reveal a profound and positive correlation between green finance and corporate financial performance. This correlation is not merely statistical but signifies a deeper, causal relationship whereby green finance acts as a crucial catalyst, fostering the economic acumen of eco-friendly enterprises through efficient capital allocation and the facilitation of vital information exchange.

A particularly noteworthy discovery of this research is the instrumental role of Research and Development (R&D) innovation as a mediator in the relationship between green financing and financial performance. Our analysis demonstrates that green finance significantly bolsters R&D activities, which in turn, enhances the innovative capabilities and financial outcomes of these firms. Furthermore, the study delves into the heterogeneity of green finance's impact, uncovering a stronger inclination towards benefiting clean energy companies and those less dependent on government subsidies. This highlights the nuanced and sector-specific nature of green finance's effectiveness, underscoring its potential to tailor financial support to the unique needs and characteristics of different eco-friendly enterprises.

5.1. Policy recommendations

Based on our findings, several policy recommendations emerge to further harness the potential of green finance for sustainable economic development. Firstly, policymakers should consider expanding and deepening the green finance market, ensuring more accessible and diversified financial instruments for eco-friendly enterprises. This could involve developing specialized green bonds, loans, and grants tailored to support R&D and innovation in sustainable technologies. Additionally, establishing clearer guidelines and incentives for green investments can attract more private capital into this sector, enhancing its overall impact.

Secondly, enhancing transparency and reporting standards around green finance activities can significantly boost investor confidence and facilitate more informed decision-making. Implementing rigorous evaluation and monitoring frameworks to assess the environmental impact of financed projects can ensure that green finance genuinely contributes to sustainable development goals.

Lastly, fostering a supportive regulatory environment that encourages collaboration between financial institutions, government bodies, and eco-friendly enterprises can enhance the effectiveness of green finance. This includes facilitating knowledge sharing, technological transfer, and capacity-building initiatives that empower firms to innovate and grow sustainably.

5.2. Limitations and future research directions

While this study provides valuable insights, it is not without limitations. The focus on Chinese eco-friendly enterprises offers a specific context that may not be directly applicable to other regions or sectors. Future research could extend this analysis to a broader set of countries, comparing the efficacy of green finance across different regulatory and economic environments. Additionally, the reliance on green-listed companies as the primary data source may overlook the experiences of smaller or unlisted firms that also engage in sustainable practices. Expanding the dataset to include a wider range of companies could offer a more comprehensive understanding of green finance's impact.

Moreover, the GMM model, while robust, is subject to certain assumptions and limitations. Future studies could employ alternative econometric techniques to validate the findings and explore the relationship between green finance and financial performance further. Investigating the role of other mediators, such as corporate governance or international market access, could also provide deeper insights into the mechanisms through which green finance influences firm performance.

This study marks a pivotal step towards integrating environmental sustainability with financial viability, demonstrating the transformative potential of green finance in supporting eco-friendly enterprises. By addressing the outlined limitations and exploring the recommended future research directions, subsequent studies can build on this foundation, advancing our understanding of sustainable finance and its role in fostering a greener economy.

CRediT authorship contribution statement

Yanru Li: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Anqiang Lin:** Writing – review & editing, Investigation, Data curation.

Declaration of competing interest

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

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