
Path Analysis of Green Finance-Driven Regional Technological Innovation in China: The Mediating Effect of R&D Investment

[Ading Li](#)^{*}, [Adul Supanut](#) finance has a positive impact on technological innovation through financial Support^{*}, [Jianxu Liu](#)

Posted Date: 7 October 2024

doi: 10.20944/preprints202410.0520.v1

Keywords: green finance; regional technological innovation; fixed effects; mediating effects; R&D investment



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article

Path Analysis of Green Finance-Driven Regional Technological Innovation in China: The Mediating Effect of R&D Investment

Ading Li ^{1,2} and Adul Supanut ^{1,*}, Jianxu Liu ³

¹ Faculty of Economics, Srinakharinwirot University, Bangkok 10110, Thailand

² School of Economics and Management, Hefei University, Hefei, Anhui Province, China

³ School of Economics, Shandong University of Finance and Economics, Jinan, Shandong Province, China

* Correspondence: adulsu@g.swu.ac.th; Tel.: +668-6063-1636

Abstracts: As the global economy pays increasing attention to sustainable development and environmental protection, the role of green finance in promoting regional technological innovation is becoming more and more prominent. This study aims to analyse the impact of green finance on regional technological innovation and its mechanism of action, with special attention to the mediating effect of R&D inputs and the moderating role of regional characteristics. By analysing the panel data of 30 provinces in China from 2008 to 2021 with fixed and mediated effect models, the results show that green finance significantly promotes regional technological innovation. R&D investment intensity partially mediates this effect, while regional innovation and entrepreneurship capacity plays a significant moderating role in this relationship. Specifically, regional innovation and entrepreneurship capacity reinforces the positive impact of green finance on R&D investment, but the marginal effect of R&D investment is reduced in regions with stronger innovation and entrepreneurship capacity. The findings provide a theoretical basis for formulating relevant policies to promote green finance development and sustainable innovation in regional economies.

Keywords: green finance; regional technological innovation; fixed effects; mediating effects; R&D investment

Introduction

Regional technological innovation is a key driving force in promoting high-quality economic development, especially in enhancing regional competitiveness, 1eason1zes industrial structure and achieving sustainable development, and plays an irreplaceable role [1]. In recent years, China's regions have attached great importance to technological innovation, continued to increase R&D investment, and gradually improved the construction of the innovation system, and the regional innovation capacity has been significantly improved. According to the latest data released by the National Bureau of Statistics, the scale of China's society-wide research and experimental development (R&D) investment reached 332.78 billion yuan in 2023, an increase of 233 times compared with 1991, with an average annual growth rate of 18.6%. At the same time, the intensity of R&D investment increased from 0.6% in 1991 to 2.64% in 2023, ranking 12th in the world (Li et al. 2024) [2]. However, along with the intensification of global climate change and the growing prominence of environmental issues, it has become a global consensus to promote the green transformation of the economy and ensure sustainable development. Countries have incorporated green development into national economic strategies, and the importance of regional technological innovation in 1eason1ze green economic transformation has become more and more prominent (Yin Hejun. 2024) [3]. In this context, it is particularly urgent and realistic to explore how green finance can 1eason1z resource allocation by guiding capital flow to the field of technological innovation, and further promote regional technological innovation through the intermediary mechanism of R&D investment. According to China Regional Science and Technology Innovation Evaluation Report

2024, China's national comprehensive science and technology innovation level index score is 78.43 points, 1.30 points higher than the previous year, the input and output index of scientific and technological activities has significantly improved, and the level of science and technology for economic and social development has continued to improve (Shayegh et al. 2023) [4].

Green finance, as an emerging financial instrument, is promoting green industry and technological innovation through the guiding role of capital flows, helping to realise green economic transformation, reduce carbon emissions and improve environmental quality. In recent years, the global green finance market has been growing rapidly, and the global green bond market has reached US\$587.6 billion in 2023, up 15% year-on-year (Climate Bonds Initiative.2024)[5]. In China, since the promotion of green finance in 2007, the scale of green credit has expanded significantly, from 7.59 trillion yuan in 2014 to 30.08 trillion yuan in 2023, with an average annual growth rate of more than 29% (People's Bank of China.2024)[6]. The rapid development of green finance not only demonstrates its potential as a driver of economic green transformation, but also provides strong financial support for regional technological innovation.

Although the relationship between green finance and regional technological innovation has gradually become the focus of research, the specific impact of green finance on regional technological innovation and its mechanism of action still need to be explored in depth. On the one hand, green finance provides the necessary financial support for the research and development and application of green technology, and promotes the development of regional technological innovation; on the other hand, regional technological innovation provides new investment opportunities and risk management tools for green finance. In particular, the role mechanism of which R&D investment as a mediating variable is still unclear. In this context, an in-depth analysis of the path of regional technological innovation driven by green finance through R&D inputs not only helps to improve green financial policies and resource allocation, but also has important theoretical and practical significance for enhancing regional innovation capacity and promoting economic green transformation. Therefore, exploring how green finance promotes regional technological innovation through the intermediary mechanism of R&D inputs is the key to understanding the relationship between green economic transformation and technological innovation, and is also the core issue of this study.

In recent years, regional innovation, as an important driving force to promote high-quality economic development, has received extensive attention from academics and policymakers. Regional innovation refers to the promotion of the flow and integration of knowledge, technology and resources within a specific geographical area through the interaction and cooperation among innovation actors such as enterprises, universities and research institutions, so as to enhance the overall innovation capacity and competitiveness of the region (Cooke et al. 1997)[7]. Studies have shown that regional innovation capacity not only helps to promote economic growth and industrial upgrading (Xu et al. 2024)[8], but also plays a key role in green development and ecological construction (Yan et al. 2023)[9]. Regional innovation not only relies on the input of science and technology R&D, but is also jointly influenced by the level of regional economic development, policy environment and innovation ecosystem (Hu et al. 2023) [10]. As the global green transition deepens, research on regional innovation is increasingly focusing on achieving sustainable development and carbon reduction goals through technological innovation (Zhang. 2023) [11]. In addition, regional innovation is closely related to the financial environment and industrial structure, especially with the support of green finance, the access to innovation funds and the promotion of technological innovation show significant synergistic effects (Lin and Zhang,2024) [12]. Therefore, exploring the role of green finance in promoting regional technological innovation, especially through the intermediary path of R&D investment to promote regional innovation, has become an important direction of current research.

As an increasingly important research area, the impact of green finance on economic development, environmental quality and carbon emissions has attracted widespread attention in recent years. Ren et al. (2020) [13] constructed a green finance development index through the indicators of green credit, green securities, green insurance and green investment, aiming to improve

the implementation of green finance policies and to promote the consumption of non-fossil energy. Zhou et al. (2020) [14] further verified the positive effects of green finance on environmental improvement, highlighting its potential in promoting sustainable economic development. Meo et al. (2021) [15] explored the relationship between green finance and carbon dioxide emissions through quantitative regression analyses, revealing the utility of green finance in supporting green energy projects and their reduction of carbon dioxide emissions. Muganyi et al. (2021) [16] studied the impacts of China's green finance policies in China and found that these policies significantly reduced industrial gas emissions, further proving the effectiveness of green finance in environmental protection. Rasoulinezhad et al. (2022) [17] used the STIRPAT model to analyse the role of green bonds in reducing carbon dioxide emissions, pointing out the positive role of green bonds in promoting green energy projects. In addition, Lv et al. (2021) [18] explored the regional disparities in the development of green finance in China and the evolution of its trends, the differences at the regional level. Lee et al. (2022) [19] investigated the impact of green finance on China's green total factor productivity, while Zhou et al. (2022) [20] explored the mediating effect of financial science and technology innovation on green growth. Irfan et al. (2022) [21] analysed the impact mechanism between green finance and green innovation, the role of regional policy interventions in green actions. Overall, these studies show that green finance plays a crucial role in improving environmental quality, reducing carbon emissions and promoting sustainable development.

With the depth of research, green finance has been widely seen as having a significant impact on promoting the green transformation of regional economies, with regional differences. Wang et al. (2021) [22] found that the establishment of green finance pilot zones significantly promoted regional green development by promoting industrial structure upgrading and technological innovation. Liu et al. (2021) [23] further integrated green finance, technological innovation, industrial structure upgrading, environment regulation and high-quality economic development into a unified framework, the central role of green finance in promoting technological innovation. Similarly, Cao et al. (2021) [24] explored the potential of digital finance in promoting green technological innovation and improving energy and environmental performance in China's regional economy, pointing out that digital transformation can enhance the environmental performance of enterprises and play a key role in green technological innovation. In addition, studies at the regional level also show that green finance has differentiated impacts on innovation in different regions. Zhang et al. (2021) [25] found that the effect of green credit on CO₂ emission reduction varies significantly across regions, whereas Ma et al. (2022) [26] by analyzing panel data, found that environmental regulation can significantly promote local green technological innovation, but the spillover effect on neighboring regions is negative. Bao et al. (2022) [27] further explored the role of green credit in promoting the green and sustainable development of regional economies, pointing out that it has an important impact on all stages of the green and sustainable development chain. The studies of Chang et al. (2023) [28] and Zhitao et al. (2023) [29] explored the mechanisms of the establishment of the Pilot Free Trade Zone (PFTZ) and the development of digital finance on the green and high-quality development, respectively, which enriched the research results on green finance in promoting regional innovation. Jiang et al. (2024) [30] further revealed the role of green finance in promoting regional innovation through industrial structure upgrading and scientific and technological development paths through an in-depth study of the mechanism of green finance on carbon emission reduction. Overall, green finance plays an important role in promoting regional technological innovation, industrial structure and improving environmental performance.

Green finance has received extensive attention in studies on mechanisms to promote regional innovation. Through a variety of ways, green finance plays an important role in promoting regional technological innovation and economic green transformation, mainly including financial support, risk sharing and incentive mechanisms. It has been shown that financial instruments such as green credit and green bonds can effectively alleviate the financing constraints of enterprises, thus promoting green technological innovation (Jiang et al., 2022) [31]. For example, the increase of green credit significantly enhances enterprises' R&D investment in environmental protection technology

and clean energy (Liu et al., 2024) [32]. Secondly, green finance reduces the risk of enterprises in green technology innovation through risk-sharing mechanisms. Instruments such as green insurance and green funds provide risk protection for enterprises and encourage them to engage in high-risk green technology R&D (Hu et al., 2023) [33]. In addition, green finance promotes the diffusion and application of green technologies through policy support and market incentives (Huang et al., 2022) [34]. The study further emphasizes the mediating role played by green finance in carbon emission reduction and pollution management, especially its significant impact in promoting green technology innovation (Cui et al., 2023) [35].

In summary, scholars have explored the impact of green finance on economic development, environmental quality, carbon emissions and regional innovation from multiple perspectives, laying a solid foundation for understanding the role of green finance in promoting sustainable development. However, with the depth of research, some shortcomings have been exposed in the existing literature. First, regarding the role of green finance in promoting regional innovation through R&D investment (Sun et al.2024) [36], the academic community has not yet formed a unified view. Some studies show that green finance can enhance R&D investment of enterprises by alleviating financing constraints, thus promoting regional innovation (Xiao et al.2023; Liu et al.2023) [37,38], but some studies point out that this role may vary according to regional differences and enterprise types (Yulin and Yahong.2023) [39]. This divergence reflects that the relationship between green finance and R&D investment may be more complex. Second, existing studies have mainly focused on the macro effects of green finance and lacked systematic analyses of its impact on regional innovation through specific R&D investment pathways (Li et al. 2024) [40]. Third, although green finance has attracted much attention in the mechanism of promoting regional innovation, few studies have explored the complex mechanism of green finance in combination with moderating variables. Most studies focus only on the overall effect, ignoring the potential role of different regional innovation and entrepreneurship capabilities in moderating the relationship between green finance and R&D investment. Finally, most of the current studies on the impact of green finance on regional innovation are limited to a single perspective and lack comprehensive analyses of multiple mechanisms and pathways.

Based on the above research gaps, this paper aims to clarify the mediating mechanism of green finance in promoting regional innovation through R&D inputs, construct the framework of its impact path, and introduce regional innovation and entrepreneurship capacity as a moderating variable to carry out the analysis of the mediating effect of moderation. Specifically, the main contributions of this study include: first, although a large number of studies have explored the impact of green finance on regional innovation, there is little literature on R&D investment as a mediating variable, and this study fills this gap on this basis. Second, it innovatively introduces regional innovation and entrepreneurship capabilities as moderating variables, and systematically analyses their moderating role in the process of green finance affecting regional innovation through R&D inputs, thus deepening the understanding of this complex mechanism. Third, based on the findings, the paper puts forward targeted policy recommendations, with a view to providing strong support for promoting green finance policies and fostering regional innovation in various regions.

The remaining chapters of this paper are arranged as follows: in the second part, the data part will be analysed in detail, covering the sources of data, the specific description of variables and the descriptive statistical analysis of data; in the third part, the construction of the model, the results of the empirical research and its analyses will be explored in depth, focusing on the impact of green finance on the regional innovation capacity, and analysing the intermediary role of the R&D investment therein; then in the fourth part, a rigorous robustness test will be carried out on the the research results are rigorously tested for robustness to guarantee the stability and credibility of the findings; finally, in the fifth part, the paper will summarise the main findings of the study and put forward practical policy recommendations based on these conclusions, and at the same time point out the shortcomings of this study and the outlook of future research.

2. Methodology

2.1. Data Sources

This study uses data from 2008 to 2021, spanning a 14-year time span, in order to analyse the impact of China's green finance practices on regional innovation capacity. Data sources include official publications and authoritative databases such as China Statistical Yearbook, China Regional Innovation Capacity Evaluation Report, China Financial Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, CSMAR database, CCEER database, and others. The reason for choosing this time period is that the Opinions on Implementing Environmental Protection Policies and Regulations to Prevent Credit Risks, issued in 2007, is regarded as the starting point of China's comprehensive green finance practice. The sample covers 30 provinces in mainland China (excluding Hong Kong, Macao, Taiwan and Tibet), totalling 420 observations. Data were selected based on availability and modelling needs, aiming to ensure the accuracy, representativeness and validity of the findings.

2.2. Introduction to Variables

2.2.1. Explained Variables

Regional Innovation Capacity (RIC). As a proxy variable for the explanatory variable regional innovation level, the composite score of the provincial-level 'Comprehensive utility value of China's regional innovation capacity' in the Report on the Evaluation of China's Regional Innovation Capacity (2008-2021), jointly published by the China Science and Technology Development Strategy Group and the Chinese Academy of Sciences, was used. Its measurements include the dimensions of provincial knowledge creation, knowledge acquisition, enterprise innovation, innovation environment and innovation performance, which can objectively evaluate the regional innovation capacity (see Table 1 for details).

Specifically, knowledge creation (15 per cent) is the cornerstone of innovation activities; knowledge acquisition (15 per cent) reflects the importance of open innovation; enterprise innovation (25 per cent), as the core driving force, directly reflects the degree of activity and effectiveness of regional innovation activities; innovation environment (25 per cent), as a supportive indicator, is the necessary guarantee for the continuation of innovation activities; and finally, innovation performance (20 per cent), as an outcome indicator, is the key basis for assessing the effectiveness of regional innovation capacity enhancement.

In summary, by adopting this comprehensive utility value as a proxy variable for regional innovation level and combining it with its multi-dimensional measurement indicators, we are able to understand and evaluate the regional innovation capacity in a more comprehensive and in-depth way, which provides a precise quantitative tool for empirical analyses, and helps to explore in-depth the internal mechanisms and external factors affecting the regional innovation capacity.

Table 1. Regional innovation capacity indicator system.

Level indicators	1	Secondary indicators	Description of indicators	causality

Regional Innovation Capacity (ric)	Knowledge creation 15 per cent	Measuring a region's ability to generate new knowledge.	positive
	Knowledge acquisition 15 per cent	Measurement of a region's ability to utilise external knowledge and cooperation between industry, academia and research.	positive
	Enterprise innovation 25 per cent	Measures the ability of firms within a region to apply new knowledge, develop new technologies, utilise new processes, and manufacture new products.	positive
	Innovation environment 25 per cent	Measure the ability of a region to provide the appropriate environment for the generation, flow and application of technology.	positive
	Innovation performance 20 per cent	The ability to measure the benefits of innovation for the economic and social development of a region.	positive

2.2.2. Explanatory Variables

Green Finance Development Index (GF), the index is constructed based on the entropy method, aiming to objectively reflect the level of green finance development. Green finance covers green loans, green securities, green insurance and green investment. In order to construct the green financial development index, this paper designs a set of index system, and objectively assigns weights to each index by entropy value method, in order to avoid the subjectivity of traditional expert scoring method. The steps of constructing green financial index by entropy value method are as follows:

①Indicator standardisation: The raw data are standardised to eliminate the effect of the scale. For positive indicators, the following formula is used for standardisation:

$$Y_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})}$$

For negative indicators, the normalisation formula is adjusted to:

$$Y_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})}$$

where X_{ij} represents the observed value of the i th indicator in the j th region; Y_{ij} is the standardised value.

② Information Entropy Calculation: The information entropy value calculates the information entropy value of each indicator using the standardized indicator value, which reflects the degree of dispersion of the indicator:

$$z_{ij} = \frac{Y_{ij}}{\sum_{j=1}^n Y_{ij}}$$

$$E_i = -\ln(n)^{-1} \sum_{j=1}^n z_{ij} \ln z_{ij}$$

③ **Determination of indicator weights:** The weights of the indicators are determined by the information entropy value W_i ;

$$W_i = \frac{1 - E_i}{\sum_{i=1}^n (1 - E_i)}$$

④ **Synthesis of green financial development index:** Finally, the green financial development composite index is calculated by combining the weights and standardized values of each indicator G:

$$G = a_{ni}W_i$$

where a_{ni} is the standardised value of the i th indicator.

Through the above steps, we obtained an objective quantitative green finance development index, which is a detailed and specific index system (as shown in Table 2), comprehensively covers multiple dimensions of green finance, accurately reflects its level of development, and lays a solid foundation of explanatory variables for the subsequent empirical analyses.

Table 2. Green finance development index indicator system.

Level indicators	1	Secondary indicators	Tertiary indicators	Description of indicators	causality
Green Finance Development Index (gf)	Green credit 50 per cent	Percentage of interest expenses in energy-intensive industries	Percentage of interest expenses in energy-intensive industries	Interest Expenditure of the Six Major Energy-Consuming Industrial Industries / Total Interest Expenditure of Industrial Industries	negative
			Percentage of New Bank Loans to A-share Listed Environmental Enterprises	New bank loans by A-share listed environmental protection companies / Loans to banks by A-share listed companies	positive
	Green securities 25 per cent	Market Capitalisation of A-share Listed Environmental Enterprises	Market Capitalisation of A-share Listed Environmental Enterprises	Market capitalisation of A-share listed environmental enterprises / Total market capitalisation of A-share listed enterprises	positive
			Percentage of A-share value of A-share listed companies with high energy consumption	Market capitalisation of A-share listed energy-intensive enterprises/total market capitalisation of A-share listed enterprises	negative

Green insurance per cent	15	Scale Environmental Pollution Insurance	Agricultural income/property income	insurance insurance	positive
		Percentage of compensation from environmental pollution insurance	Agricultural expenditure/income from agricultural insurance	insurance from	positive
Green investments per cent	10	Percentage of investment in environmental pollution control	Investment in environmental pollution control/GDP		positive
		Percentage of fiscal expenditure on environmental protection	Fiscal expenditure on environmental protection/total fiscal expenditure		positive

2.2.3. Control Variables

In order to ensure the accuracy of the estimation of the impact of green finance on regional innovation, the selection of control variables in this paper takes full account of the region's basic innovation environment, actual resource inputs and external environment. Specifically, a series of control variables including industrial structure (ind), human capital (Inhes), urbanisation level (ur), science and technology emphasis (techi), carbon emissions (Inco2) and capital investment (capi) are introduced, and the following theoretical and empirical bases support the choice of these variables.

Firstly, industrial structure plays a key role in technological innovation. According to the theory of industrial economics, regions with a higher share of service and high-technology industries usually have stronger innovation capacity (Ge et al. 2023) [41]. Therefore, incorporating industrial structure as a control variable can more accurately measure the innovation potential of the region. Human capital directly affects the quality of regional human capital, which is the basic element to promote technological innovation. The higher the human capital, the stronger the region's innovation and technology absorption capacity, so the article needs to use it as a control variable. The level of urbanisation is also an important factor affecting regional innovation, as the urbanisation process is able to gather innovative resources and promote the diffusion and application of knowledge and technology, and controlling for this variable is crucial to accurately assessing innovation capacity.

In addition, the level of emphasis on science and technology is an important indicator of the level of support for innovation activities in a region. Higher S&T investment usually

implies a stronger incentive to innovate, so this variable is crucial for an accurate assessment of regional innovation capacity. Carbon emissions, as a control variable for environmental factors, influence the demand and direction of green technology innovation, and controlling for this variable helps to exclude the external effects of environmental pressures on innovation activities. Finally, capital investment is a key resource for firms to carry out R&D and innovation activities, and regions with sufficient capital are more likely to support large-scale innovation activities, so controlling for capital investment helps to avoid overestimation or underestimation of innovation capacity due to regional capital differences.

By introducing these control variables, the analyses in this paper can reflect the actual impact of green finance on regional innovation more comprehensively and accurately, ensuring the robustness and reliability of the research results. In addition, this paper adopts a fixed-effects double clustering (Cluster) regression model to control for the invariant effects of province and time, thus further enhancing the robustness of the research results. Details of each variable are detailed in Table 3.

Table 3. Variable definitions and descriptions.

variable name	variable symbol	Variable Definition
Regional innovation capacity	ric	Calculated by the Weighted Integrated Evaluation Method
Green Finance Development Index	gf	entropy weighting
industrial structure	ind	Value added of secondary sector/GDP
human capital	Inhes	Logarithmic number of general higher education institutions
urbanisation level	ur	Urban/resident population
Science and technology focus	techi	Local finance science and technology expenditure/local finance general budget expenditure
carbon footprint	Inco2	Logarithmic carbon dioxide emissions by province and region
capital investment	capi	Investment in Fixed Assets/Gross Regional Product

2.2.4. Mediating and Moderating Variables

In this study, the mediating variable is the intensity of R&D investment (RD), which serves as a key indicator of regional innovation capacity and reflects the level of regional financial investment in S&T innovation. This variable is quantified by the ratio of R&D expenditure to regional gross domestic product (GDP), which reveals the level of regional emphasis on S&T R&D activities and its support for the innovation-driven development strategy. Theoretical analyses anticipate that the development of green finance may indirectly promote regional technological innovation capacity by enhancing the intensity of R&D investment, thus establish an intrinsic link between green finance and regional technological innovation.

Research and development (R&D) investment intensity (RD) is selected as a mediator variable, aiming to explore how green finance can enhance regional innovation capacity by promoting R&D activities. The importance of R&D investment in promoting technological innovation has been widely recognised, and both the Diffusion of Innovation Theory (ROGERS 1962) [42] and the Resource Base Theory (Wernerfelt 1984) [43] emphasise that R&D investment is the core driver of technological innovation and maintaining competitive advantage for enterprises. By increasing R&D investment, firms can develop new technologies and improve products more effectively, thus enhancing their overall innovation capability. Therefore, RD as a mediating variable is of great significance in this study. In addition, existing empirical studies have shown that RD investment has a significant mediating role between green finance and technological innovation, especially in resource-intensive and technology-intensive industries, and this mechanism is particularly obvious (Tang et al. 2023) [44]. The introduction of RD as a mediating variable not only helps to reveal the path of green finance affecting regional innovation, but also fills the research gap in the existing literature in exploring the specific mechanism between green finance and innovation.

In this paper, the regional innovation and entrepreneurship capacity (IU) was selected as a moderating variable, aiming to deeply explore the impact of green finance on regional innovation. As an intrinsic factor, regional innovation and entrepreneurship capacity (IU) reflects the ability of enterprises and individuals in the region in innovative ideas, technological development and entrepreneurial activities. According to the theory of diffusion of innovation, regions with stronger innovation and entrepreneurship capabilities are more active in technological innovation activities, and green finance is more likely to play a significant facilitating role in such regions. Therefore, IU can moderate the relationship between green finance and regional innovation, and further promote the research, development and application of green technologies by enhancing the innovation atmosphere.

Combining these mediating and moderating variables, this study aims to reveal the complex interaction mechanism between green finance and regional technological innovation. Through rigorous empirical analyses, this study can not only provide a supplement to existing theories, but also provide policymakers with strong decision support in promoting green transformation and technological innovation in regional economies.

2.3. Data Description

To ensure the stability and accuracy of the data, this paper performs logarithmic transformation on the sample variables and applies a 1% Winsorizing treatment to the continuous variables. Descriptive statistical analysis based on 420 observations shows that the mean value of regional innovation capacity (*lnric*) is 3.359, with a standard deviation of 0.309, indicating that there are significant differences in the innovation capacity of regions; the median is 3.315, implying that the innovation capacity of most of the regions is relatively low, and needs to be further improved. The mean value of the green financial development index (*gf*) is 0.152, with a standard deviation of 0.063, and the median is slightly lower than the mean, suggesting that the development of green finance in most regions is still at a low level and is more widely distributed (the minimum value is 0.072, and the maximum value is 0.450). Control variables, such as industrial development (*ind*), human capital (*hes*), urbanisation rate (*ur*) and technological level (*techi*), show some regional variability, which may affect regional innovation capacity. The large fluctuations in carbon dioxide emissions (*co2*) suggest the need to consider the role of environmental factors on technological innovation, while the relative stability of capital investment (*capi*) may indicate its supportive role in technological innovation. Detailed statistical results are shown in Table 4.

Table 4. Descriptive statistics of variables.

variable	N	mean	p50	sd	min	max
<i>lnric</i>	420	3.359	3.315	0.309	2.820	4.197
<i>gf</i>	420	0.152	0.136	0.063	0.072	0.45

ind	420	0.418	0.427	0.083	0.16	0.62
hes	420	84.14	83.5	38.48	9	167
ur	420	0.575	0.557	0.131	0.291	0.896
techi	420	0.021	0.013	0.015	0.004	0.072
co2	420	362.3	265.9	305	32.12	2100
capi	420	0.138	0.128	0.057	0.0450	0.457

To detect the problem of multicollinearity in the model, the variance inflation factor (VIF) and tolerance (Tolerance) were calculated in this study. Table 5 shows the VIF values and Tolerance of the respective variables. From the results in Table 5, the VIF values for all the variables are below 3, with a maximum value of 2.93 (variable techi), which is much lower than the commonly used threshold value of 10. The average VIF value of 2.01 is also at a low level, which indicates that the problem of multicollinearity in this model is not significant. In addition, the tolerance of each variable is greater than 0.1 (minimum value of 0.341, variable techi), which also indicates that there is no significant covariance problem among the independent variables of the model.

Table 5. Multiple covariance test.

Variable	VIF	Tolerance
gf	1.30	0.770
ind	1.79	0.559
Inhes	2.19	0.456
ur	2.58	0.387
techi	2.93	0.341
Inco2	2.10	0.475
capi	1.18	0.849568
Mean VIF	2.01	/

2.4. Empirical Model

2.4.1. Fixed Effects Model

In order to comprehensively explore the impact of green finance on regional innovation capacity, this study adopts a fixed effects model with the basic model set as follows:

$$RIC_i = \alpha_0 + \alpha_1 GF_{it} + \alpha_2 control_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad (1)$$

which RIC_i Represents regional innovation capacity; GF_{it} represents green finance, and $control_{it}$ are the control variables, the λ_i and μ_t represent regional and year control variables, respectively; ϵ_{it} represents the random error term.

2.4.2. Mediated Effects Model

In order to deeply investigate the internal transmission mechanism of "green finance - regional innovation capacity", this study constructs the following recursive equation system to analyse how green finance affects regional innovation capacity through R&D investment intensity (RD):

Effect of green finance on mediating variables (path a).

$$RD_{it} = \delta_0 + \delta_1 GF_i + \delta_2 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad (2)$$

Impact of mediating variables on regional innovation capacity (path b).

$$RIC_i = \epsilon_0 + \epsilon_1 RD_{it} + \epsilon_2 GF_i + \epsilon_3 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad (3)$$

where RD_{it} is the mediating variable. Following the research line of Wen and Ye (2014) [45], the first step is to verify the coefficient δ_1 in equation (2) and the coefficient ε_1 in equation (3). If both coefficients exist, the mediating effect is significant; the second step verifies the coefficient ε_2 in equation (3), if it is significant, it indicates the existence of partial mediation effect, otherwise it is a full mediation effect; the third step compares δ_1 and $\varepsilon_1\varepsilon_2$ sign, if the sign is same, it is a partial mediation effect, the weight of the mediation effect is $\delta_1\varepsilon_1 / \alpha_1$. The third step is to compare the signs of δ_1 and $\varepsilon_1\varepsilon_2$. If the sign is different, it is a masking effect, and the proportion of the mediating effect is $|\delta_1\varepsilon_1 / \alpha_1|$.

2.4.3. Modelling the Mediating Effects of Regulation

In order to investigate the effect of moderating variables on the mediating effect, this study constructed a mediating effect model of moderation:

$$RD_{it} = a_0 + a_1GF_i + a_2W_{it} + a_3(GF_{it} \times W_{it}) + a_4Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad (4)$$

$$RIC_i = b_0 + b_1GF_i + b_2M_{it} + b_3W_{it} + b_4(GF_{it} \times W_{it}) + b_5(RD_{it} \times W_{it}) + b_6Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad (5)$$

According to the test of Wen and Ye (2014) [46], the coefficient a_3 of the interaction term in equation (4) is first tested. If it is significant, it indicates that the moderator variable (W) has a moderating effect on the relationship between the independent variable (GF) and the mediator variable (RD_{it}); then verify the coefficient b_5 of the interaction term in Equation (5), which, if significant, indicates that the moderator variable (W) has a moderating effect on the relationship between the mediator variable (RD_{it}) and the dependent variable (RIC), thus proving that there is a mediating effect of moderation. The path diagram of the relevant influence mechanism is shown in Figure 1:

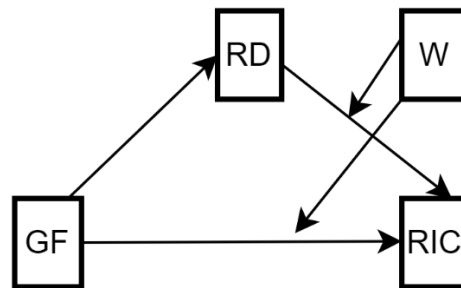


Figure 1. Impact mechanism pathway diagram.

3. Empirical Results

3.1. Analysis of Baseline Regression

This study first tests the direct effect of green finance (gf) on regional innovation capacity (lnric), hypothesising that green finance can promote regional innovation capacity. To this end, this paper constructs a variety of fixed effects models to test the hypothesis. The following are the results of the baseline regression analyses of the impact of green finance on regional innovation capacity, which are detailed in Table 6.

In Model 1, only the explanatory variable green finance (gf) is included in this paper. The results show that the regression coefficient of gf is 1.315 and significant at the 1% statistical level, indicating that the development of green finance has a significant positive contribution to regional innovation capacity. However, the goodness of fit of model 1 is low, with an adjusted R^2 of 0.067, indicating that the explanatory power of the model is more limited when only green finance is considered.

Model 2 adds province fixed effects and year fixed effects to model 1. The results show that the regression coefficient of green finance decreases to 0.214, but is still significant at the 1% statistical

level. The adjusted R^2 of Model 2 significantly increases to 0.944, showing that the introduction of province and year fixed effects significantly enhances the explanatory power of the model.

Model 3 further introduces control variables based on model 1. After adding these control variables, the regression coefficient of green finance is 0.148, although no longer significant, but other control variables such as industrial structure, science and technology inputs and capital inputs have a significant positive impact on regional innovation capacity at the 1% statistical level, while carbon emissions have a significant negative impact on regional innovation capacity at the 5% level. The adjusted R^2 of model 3 is 0.771, indicating that the control variables have a certain enhancement on the explanatory power of the model.

Model 4 further adds control variables to model 2, and the results show that the regression coefficient of gf is 0.207 and is significant at the 1 per cent statistical level. This indicates that green finance still has a significant positive effect on regional innovation capacity even when controlling for both province and year fixed effects and multiple control variables. The adjusted R^2 of model 4 further increases to 0.954, indicating that the model has stronger explanatory power and robustness.

Overall, the results of the baseline regression analyses indicate that green finance has a significant positive contribution to regional innovation capacity, and the finding remains robust after the inclusion of control variables and fixed effects. This suggests that green finance is an important factor in promoting regional innovation.

Table 6. Baseline regression results.

	Model 1	Model 2	Model 3	Model 4
	lnric	lnric	lnric	lnric
gf	1.315*** (0.235)	0.214*** (0.052)	0.148 (0.133)	0.207*** (0.052)
ind			0.742*** (0.118)	0.757*** (0.133)
lnhes			0.174*** (0.017)	0.142** (0.057)
ur			0.337*** (0.089)	0.252 (0.300)
techi			13.187*** (0.850)	2.097*** (0.477)
lnco2			-0.070*** (0.013)	-0.029* (0.015)
capi			0.427*** (0.138)	0.500*** (0.082)
Constant	3.159*** (0.039)	3.326*** (0.008)	2.142*** (0.095)	2.309*** (0.211)
N	420	420	420	420
R ²	0.069	0.950	0.775	0.960
Prov FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES
r ² _a	0.067	0.944	0.771	0.954

Note: *, **, *** indicate significant at the 10 per cent, 5 per cent, and 1 per cent levels, respectively; standard errors are in () in the table.

3.2. Analysis of Mediating Effects

This study further explores the mediating role of R&D investment intensity (rd) in the impact of green finance (gf) on regional innovation capacity (lnric). We hypothesise that green finance enhances regional innovation capacity by promoting an increase in R&D investment. To test this hypothesis, we constructed a regression model (Model 5) with mediating variables.

In Model 5, we find that green finance has a significant positive effect on R&D investment intensity (coefficient of 0.004, $p < 0.1$), indicating that green finance can effectively incentivise regions to increase R&D investment. In addition, the positive effect of R&D investment intensity on regional innovation capability (lnric) is also confirmed (coefficient of 9.464, $p < 0.01$), suggesting that R&D investment is an important driver of regional innovation capability. Nevertheless, the coefficient of green finance is still significant (coefficient of 0.168, $p < 0.05$), suggesting that there is a partial mediating effect. The Sobel Z-value of mediating effect is 2.347 ($p < 0.05$), the bootstrap Z-value is 2.13 ($p < 0.05$), and the mediating effect accounts for 49% of the total, and all these results indicate that R&D investment intensity plays a partially mediating role in the impact of green finance on regional innovation capacity. In short, green finance not only directly promotes the enhancement of regional innovation capacity, but also indirectly promotes it by increasing the intensity of R&D investment, where the intensity of R&D investment plays a significant mediating role.

In addition, this study explores the moderating mediating effect of regional innovation and entrepreneurship (lniu) in the mechanism of green finance affecting regional innovation capacity through R&D investment intensity. We hypothesise that regional innovation and entrepreneurship capacity may influence the impact of green finance on R&D inputs, which in turn changes the mediating effect of R&D inputs on regional innovation capacity. To test this hypothesis, we constructed a moderated mediation effect model (Model 6) containing interaction terms based on the mediation effect model.

In Model 6, the coefficient of the interaction term ($gf \times lnui$) for regional innovation and entrepreneurship capacity (lniu) is 0.015, which is significant at the 10% significance level ($p < 0.10$), suggesting that regional innovation and entrepreneurship capacity significantly enhances the positive impact of green finance on R&D inputs, which may further enhance the mediating effect of green finance on regional innovation capacity through R&D inputs. In addition, the positive effect of R&D investment on regional innovation capacity is also significant (coefficient of 11.469, $p < 0.01$). The results of both the Sobel test and the bootstrap test indicate that the mediation effect of regulation is significant (Sobel Z value of 2.103, $p < 0.05$; bootstrap Z value of -1.98, $p < 0.05$), and the mediation effect under moderation is 39.8%. All these results indicate that regional innovation and entrepreneurship capacity plays a moderating role in the mechanism of green finance's influence on regional innovation capacity, and this moderating role is realised through the mediating variable R&D input.

Table 7. Mediated effects test.

	Model 5		Model 6	
	rd	lnric	rd	lnric
gf	0.004* (0.002)	0.168** (0.068)	-0.063* (0.031)	-1.609* (0.891)
rd		9.464*** (2.781)		11.469*** (3.368)
lniu			-0.006*** (0.001)	0.051 (0.046)
gf×lniu			0.015* (0.007)	0.412* (0.197)

control variable	YES	YES	YES	YES
Constant	0.015*** (0.004)	2.171*** (0.203)	0.026*** (0.005)	2.299*** (0.293)
N	420	420	420	420
R ²	0.945	0.961	0.951	0.963
Prov FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
r2_a	0.938	0.956	0.944	0.957
Sobel Z	2.347		2.103	
Sobel Z-p value	0.019		0.035	
bootstrap Z	2.13		1.98	
bootstrap Z-p value	0.033		0.048	
Percentage of intermediary effects	49 per cent		39.8 per cent	

Note: *, **, *** indicate significant at the 10 per cent, 5 per cent, and 1 per cent levels, respectively; standard errors are in () in the table.

The quantile moderated mediation effect analysis further reveals the moderating role of regional innovation and entrepreneurship capability (lniu) on the mediation effect of research and development (R&D) investment (RD) at different quantile levels. Figure 2 shows that the coefficient of RD investment is higher at lower quartile levels of lnui, indicating that RD investment plays a more significant role in promoting regional innovation in regions with lower regional innovation and entrepreneurship capabilities. However, this impact coefficient shows a gradual decline as the lnui quartile increases and is no longer significant at the 90 per cent quartile. This finding suggests that the marginal promotional effect of R&D investment is weakened in regions with higher regional innovation and entrepreneurship capabilities, probably because other innovation drivers are more prominent in a high level of lnui, which relatively reduces the strength of the impact of R&D investment.

In summary, the results of the mediation effect analysis and quartile moderated mediation effect analysis in this study indicate that regional innovation and entrepreneurship (lniu) plays a significant moderating role in the process of green finance affecting regional innovation capacity through R&D investment intensity. The mediating effect of R&D inputs is more significant at lower quartile levels of lnui, while it is weakened at higher quartile levels. These findings provide insights into understanding the mechanism of green finance's effect on regional innovation and provide important references for the formulation of more targeted policies.

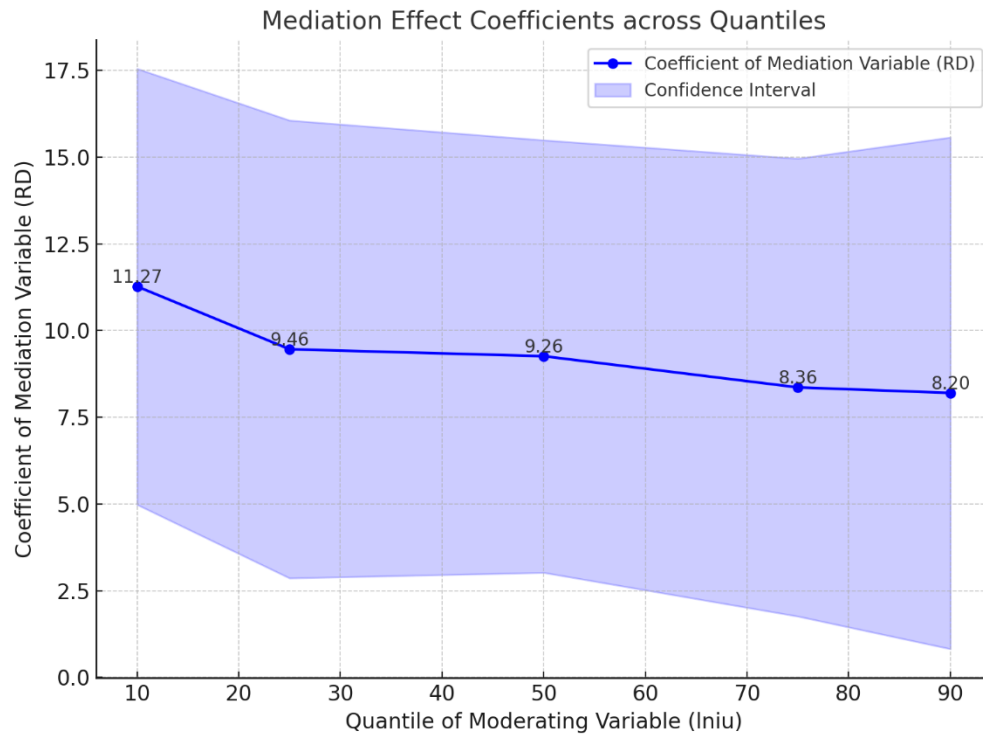


Figure 2. Quantile Moderation Effect Plot.

4. Robustness Tests

In Table 8, the impact of green finance on regional innovation capacity (Inric) is analysed through three types of robustness tests, and the results show that the model is highly robust and consistent.

Firstly, the results of Bootstrap method (column 1 of Table 8) show that the regression coefficient of green finance (gf) is 0.207 and significant at 1% significance level ($p < 0.01$). This indicates that the positive impact of green finance on regional innovation capacity is effectively verified by sampling test through Bootstrap method, which enhances the reliability of the model results.

Secondly, robustness is verified by the replacement variable method (columns 2-5 of Table 8). In column 2, replacing regional innovation capacity with corporate innovation (Inci) as the explanatory variable, the regression coefficient of green finance is significantly increased to 0.684 ($p < 0.01$), indicating that green finance plays a more prominent role at the micro level (e.g., corporate innovation), which supports the theory that green finance promotes corporate-level innovation. In column 3, using the first-order lagged term of green finance (gfl1) as the dependent variable, the regression coefficient is 0.243 ($p < 0.01$), which maintains significance, confirming that the lagged effect of green finance has a positive impact on regional innovation capacity, further confirming the robustness of the lagged effect. In column 4, after adjusting and replacing the control variables, the regression coefficient of green finance is 0.614 ($p < 0.01$), indicating that the impact of green finance on regional innovation capacity remains significant and stable even if the control variables are changed. In column 5, we further enrich the model by including the following additional control variables:

The degree of openness to the outside world (od), measured as the ratio of total imports and exports to GDP of the location of the business unit, reflects the degree of openness of the regional economy and the degree of integration into the international market, which may have an impact on regional innovation capacity.

The degree of attention to environmental protection (ep), measured by the ratio of local financial expenditure on environmental protection to the general budget expenditure of local finance, reflects the local government's financial investment in environmental protection, which may be related to the effect of the role of green finance.

Traditional financial development (fd), measured as the ratio of value added of the financial industry to GDP, represents the level of development of the traditional financial sector, and its interaction with green finance may affect regional innovation capacity.

Area size (lnsize), which uses the natural logarithm of the number of household population at the end of the year as a proxy variable, reflects the size of the area, which may affect the clustering of innovation resources and the development of innovation activities.

In the model in column 5, the regression coefficient for green finance is 0.573 ($p < 0.01$), and the effect of green finance on regional innovation capacity remains significant even in the complex model setup that takes into account these additional control variables, which provides further evidence of the original findings and demonstrates the robustness of the model under more comprehensive variable considerations.

Finally, the robustness test conducted by shortening the time window (column 6) to the last ten years (2012-2021) shows that the regression coefficient of green finance increases to 0.773 ($p < 0.01$), and the significance level remains at 1%. This result indicates that green finance contributes more significantly to regional innovation capacity in a shorter time frame, further demonstrating the applicability and robustness of the model across different time periods.

In summary, the results of the above three types of robustness testing methods all show the significance and consistency of the impact of green finance on regional innovation capacity, proving the robustness of the research model and the reliability of the results. These findings further support the important role of green finance in promoting regional innovation and provide strong theoretical support for the formulation of related policies.

Table 8. Robustness tests.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	lnric	lnci	lnric	lnric	lnric	lnric
gf	0.207*** (0.053)	0.684*** (0.180)		0.614*** (0.156)	0.573*** (0.163)	0.773*** (0.200)
gfl1			0.243*** (0.059)			
ind	0.757*** (0.135)	1.562*** (0.500)	0.834*** (0.131)		1.286** (0.519)	3.019*** (0.590)
is				-1.705*** (0.462)		
lnhes	0.142** (0.059)	-0.213 (0.255)	0.144* (0.071)		-0.413 (0.263)	-0.552 (0.330)
hep				-35.255 (26.260)		
ur	0.252 (0.301)	0.636 (0.760)	0.100 (0.308)	0.294 (0.842)	2.822** (1.094)	2.742 (1.694)
techi	2.097*** (0.475)	4.302** (1.762)	2.225*** (0.493)	5.425*** (1.483)	2.040 (1.358)	4.526* (2.284)
lnco2	-0.029* (0.015)	-0.028 (0.049)	-0.036* (0.018)		-0.069 (0.048)	-0.095 (0.058)
lnso2				0.086* (0.042)		
capi	0.500***	0.997**	0.497***	1.135***	0.844**	0.730*

	(0.088)	(0.354)	(0.111)	(0.348)	(0.339)	(0.374)
od					-0.521**	
					(0.176)	
ep					-0.516	
					(1.455)	
fd					-0.323	
					(1.347)	
Insize					0.887*	
					(0.449)	
Constant	2.309***	3.076**	2.380***	3.524***	-3.983	3.066***
	(0.213)	(1.060)	(0.219)	(0.454)	(3.251)	(0.887)
Observations	420	420	390	420	420	300
R-squared	0.960	0.868	0.960	0.871	0.880	0.893
Prov FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
r2_a	0.960	0.851	0.955	0.853	0.863	0.874

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5. Conclusions

This study constructs a green finance development index and employs fixed effects models, mediation models, and moderated mediation models to conduct an empirical analysis of panel data from 30 provinces in China from 2008 to 2021. The analysis investigates the mechanisms through which green finance influences regional technological innovation, with a particular focus on the mediating role of R&D investment and the moderating role of regional innovation and entrepreneurship capabilities. The results indicate that green finance has a significant positive impact on regional technological innovation, with part of this effect being realized through increased R&D intensity. Moreover, regional innovation and entrepreneurship capabilities significantly moderate this relationship. Specifically, higher innovation and entrepreneurship capabilities enhance the positive effect of green finance on R&D investment, though the marginal effect of R&D on innovation may diminish in regions with stronger capabilities.

This research uncovers the multi-level mechanisms by which green finance affects regional technological innovation, highlighting the critical mediating role of R&D investment and the complex interactions of moderating variables in different contexts. These findings offer new insights and empirical evidence for understanding how green finance drives regional innovation. Based on these results, the study proposes several policy recommendations. First, the government should establish dedicated green finance innovation funds to support R&D and innovation projects in environmental technology companies, particularly those that significantly enhance regional innovation capacity. This will alleviate financial pressures on companies engaged in green technology development and foster technological breakthroughs. Second, the government should further improve green finance-related policies by offering more favorable tax and loan incentives, encouraging financial institutions and enterprises to actively participate in green finance initiatives, thus promoting regional technological innovation. Third, local governments and businesses should increase their support for innovation and entrepreneurship, especially in regions with weaker capabilities, by providing policy guidance and resource allocation to strengthen overall regional innovation capacity and amplify the effect of green finance on R&D investment. Lastly, collaboration between green finance institutions and scientific research institutes, universities, and other innovation stakeholders should be promoted to establish synergistic innovation mechanisms. Such cooperation will optimize the allocation of green finance resources and accelerate the industrialization and application of research outcomes.

These policy recommendations will not only contribute to the deepening of green finance but will also effectively promote regional technological innovation, facilitating the green transformation of the economy and sustainable development. Their implementation will ensure that the potential of green finance to drive innovation is fully realized, providing robust support for green transition and high-quality development.

While this study provides new perspectives on the relationship between green finance and regional technological innovation, there remains room for further exploration. The current research focuses on provincial-level data, and future studies could extend to the firm level, offering more detailed insights into how green finance shapes the trajectory of firm-level technological innovation. Additionally, future research could examine other potential mediators, such as human capital and intellectual property protection. Given the ongoing development of green finance policies, it is also essential to consider the long-term effects. Therefore, future research should adopt a more micro-level perspective, explore a broader range of mediating factors, and extend the time frame to build a more comprehensive and in-depth understanding.

References

1. Li H, Liu J, Wang H. Impact of green technology innovation on the quality of regional economic development. *International Review of Economics & Finance*. 2024 Jun 1;93:463-76.[CrossRef]
2. Yin Hejun. China's R&D expenditure exceeds 3.3 trln yuan in 2023: minister. *Xinhua*, 5 Mar 2024. Available online: <https://english.news.cn/20240305/d3d97f55bdf44d40a49d9ae2224ce0dc/c.html> (accessed on 26 Setember 2024).
3. Shayegh S, Reissl S, Roshan E, Calcaterra M. An assessment of different transition pathways to a green global economy. *communications Earth & Environment*. 2023 Nov 29;4(1):448.[CrossRef]
4. China Science and Technology Strategy Research Institute. (2024). *China Regional Science and Technology Innovation Evaluation Report 2024*[M]. Beijing: China Science and Technology Strategy Research Institute. (In Chinese)
5. Climate Bonds Initiative. (2024). *Global State of the Market Report 2023*. Available online:<https://www.climatebonds.net/resources/reports/global-state-market-report-2023>(Available online:(accessed on 26 Setember 2024).
6. People's Bank of China. (2024). China's green loan balance exceeds 30 trillion yuan. *People's Daily Overseas Edition*. Available online: https://www.gov.cn/lianbo/bumen/202401/content_6928561.htm(accessed on 26 Setember 2024). (In Chinese)
7. Cooke P, Uranga MG, Etxebarria G. Regional innovation systems: institutional and organisational dimensions. *research policy*. 1997 Dec 1;26(4-5). 475-91.[CrossRef]
8. Xu L, Shu H, Lu X, Li T. Regional technological innovation and industrial upgrading in China: an analysis using interprovincial panel data from 2008 to 2020. *Finance Research Letters*. 2024 Jun 5:105621.[CrossRef]
9. Yan, X.; Sun, Q. How to Evaluate Ecological Civilization Construction and Its Regional Differences: Evidence from China. *Sustainability* **2023**, *15*, 12543.[CrossRef]
10. Hu B, Guo P, Gao M. Enhancing high-quality development in regional innovation ecosystems. *Physics and Chemistry of the Earth, Parts A/B/C*. 2023 Dec 1 ;132:103488. [CrossRef]
11. Zhang, Y. The Sustainability of Regional Innovation in China: Insights from Regional Innovation Values and Their Spatial Distribution. *Sustainability* **2023**, *15*, 10398. [CrossRef]
12. Lin B, Zhang A. Digital finance, regional innovation environment and renewable energy technology innovation: Threshold effects. *Renewable Energy*. 2024 Mar 1;223:120036.[CrossRef]
13. Ren X, Shao Q, Zhong R. Nexus between green finance, non-fossil energy use, and carbon intensity: Empirical evidence from China based on a vector *Journal of Cleaner Production*. 2020 Dec 20;277:122844. [CrossRef]
14. Zhou X, Tang X, Zhang R. Impact of green finance on carbon intensity. Zhang R. Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China. *Science and Pollution Research*. 2020 Jun;27:19915-32. [CrossRef]
15. Meo MS, Abd Karim MZ. The role of green finance in reducing CO2 emissions: an overview. *finance in reducing CO2 emissions: an empirical analysis*. *Borsa Istanbul Review*. 2022 Jan 1;22(1):169-78. [CrossRef] <https://doi.org/10.1016/j.bir.2021.03.002>
16. Muganyi T, Yan L, Sun HP. Green finance, fintech and environmental protection: Evidence from China. *Ecotechnology*. 2021 Jul 1;7:100107.[CrossRef]
17. Rasoulinezhad E, Taghizadeh-Hesary F. Role of green finance in improving energy efficiency and renewable energy development. *energy Efficiency*. 2022 Feb;15(2):14. [CrossRef]

18. Lv C, Bian B, Lee CC, He Z. Regional gap and the trend of green finance development in China. *energy Economics*. 2021 Oct 1;102:105476. [CrossRef]
19. Lee CC, Lee CC. How does green finance affect green total factor productivity? Evidence from China. *energy economics*. 2022 Mar 1;107:105863. [CrossRef]
20. Zhou G, Zhu J, Luo S. The impact of fintech innovation on green growth in China: Mediating effect of green finance. *Ecological Economics*. 2022 Mar 1;193:107308. [CrossRef]
21. Irfan M, Razzaq A, Sharif A, Yang X. Influence mechanism between green finance and green innovation: exploring regional policy intervention effects in China. *Technological Forecasting Technological Forecasting and Social Change*. 2022 Sep 1;182:121882. [CrossRef]
22. Wang Y, Zhao N, Lei X, Long R. Green finance innovation and regional green development. *innovation and regional green development. sustainability*. 2021 Jul 23;13(15):8230. [CrossRef]
23. Liu Y, Lei J, Zhang Y. A study on the sustainable relationship among the green finance, environment regulation and green-total-factor productivity in China. *Sustainability*. 2021 Oct 28;13(21):11926. [CrossRef]
24. Cao S, Nie L, Sun H, Sun W, Taghizadeh-Hesary F. Digital finance , green technological innovation and energy-environmental performance: evidence from China's regional economies. *journal of cleaner production*. 2021 Dec 10;327:129458. [CrossRef]
25. Zhang W, Hong M, Li J, Li F. An examination of green credit promoting carbon dioxide emissions reduction: a provincial panel analysis of China. *Sustainability*. 2021 Jun 25;13(13):7148. [CrossRef]
26. Ma R, Li F, Du M. How does environmental regulation and digital finance affect green technological innovation: Evidence from China. *Frontiers in Environmental Science*. 2022 May 31;10:928320. [CrossRef]
27. Bao J, He M. Does green credit promote green sustainable development in regional economies?-Empirical evidence from 280 cities in China. *PLoS One*. 2022 Nov 10;17(11). e0277569. [CrossRef]
28. Chang Y, Wang S. China's pilot free trade zone and green high-quality development: An empirical study from China. *development: An empirical study from the perspective of green finance. Environmental Science and Pollution Research*. 2023 Aug;30(38):88918-35. [CrossRef]
29. Zhitao Z, Khan AA, Khan SU, Ali MA, Zonglin W, Luo J. Untangling the causal mechanisms and spatial dynamics of digital financial development's impact on energy intensity: insights from panel data of Chinese provinces. *environmental Science and Pollution Research*. 2023 Sep;30(42):96147-62. [CrossRef]
30. Jiang P, Xu C, Chen Y. Can green finance reduce carbon emission? A theoretical analysis and empirical evidence from China. *Pollution Research*. 2024 May 10:1-6. [CrossRef]
31. Jiang S, Liu X, Liu Z, Shi H, Xu H. Does green finance promote enterprises' green technology innovation in China? *Frontiers in Environmental Science*. 2022 Aug 16;10:981013. [CrossRef]
32. Liu F, Xia Z, Lee CC. Does green credit benefit the clean energy technological innovation and how? The policy catering behaviour of enterprises. *Journal of Cleaner Production*. 2024 Mar 10;444:141256. [CrossRef]
33. Hu Y, Du S, Wang Y, Yang X. How does green insurance affect green innovation? Evidence from China. *sustainability*. 2023 Aug 9;15(16):12194. [CrossRef]
34. Huang Y, Chen C, Lei L, Zhang Y. Impacts of green finance on green innovation: a spatial and nonlinear perspective. *Journal of Cleaner Production. Journal of Cleaner Production*. 2022 Sep 10;365:132548. [CrossRef]
35. Cui Y, Zhong C, Cao J, Guo M. Can green finance effectively mitigate PM2. 5 pollution? What role will green technological innovation play? *Energy & Environment*. 2023:0958305X231204030. [CrossRef]
36. Sun H, Luo Y, Liu J, Bhuiyan MA. Digital inclusive finance, R&D investment, and green technology innovation nexus. *Plos one*. 2024 Jan 19;19(1). *Plos one*. 2024 Jan 19;19(1): e0297264. [CrossRef]
37. Xiao Y, Shi X, Kong L. From green finance to sustainable innovation: how to unleash the potential of China's high-tech industry. *Environmental Science and Pollution Research*. 2023 Dec;30(59):123368-82. [CrossRef]
38. Liu C, Dai C, Chen S, Zhong J. How does green finance affect the innovation performance of enterprises? Evidence from China. *Environmental Science and Pollution Research*. 2023 Jul;30(35):84516-36. [CrossRef]
39. Yulin W, Yahong Z. Green Finance Development and Enterprise Innovation *Journal of Finance and Economics*. 2023 Jan 3;49(01):49-62. Available online: <https://link.oversea.cnki.net/doi/10.16538/j.cnki.jfe.20220615.101> (accessed on 1 Oct 2024).
40. Li L, Ma X, Ma S, Gao F. Role of green finance in regional heterogeneous green innovation: evidence from China. *Humanities and Social Sciences Communications*. 2024 Aug 7;11(1):1-3. [CrossRef]
41. Ge L, Li C, Sun L, Hu W, Ban Q. The Relationship between High-Tech Industrial Agglomeration and Regional Innovation: a Meta-Analysis Investigation in China. *Sustainability*. 2023 Dec 4;15(23):16545. [CrossRef]
42. ROGERS E M. *Diffusion of Innovations* [M]. New York: Free Press, 1962 .
43. Wernerfelt B. A resource-based view of the firm [J]. *Strategic management journal*, 1984 , 5(2): 171-180. [CrossRef]
44. Tang D, Yan J, Sheng X, Hai Y, Boamah V. Research on green finance, technological innovation, and industrial structure upgrading in the Yangtze River Economic belt. *Sustainability*. 2023 Sep 17;15(18):13831. [CrossRef]

45. Wen Z, Ye B. Analyses of mediating effects: the development of methods and models. *Advances in psychological Science*. 2014 May 15;22(5):731. [CrossRef]
46. Wen Z, Ye B. Different methods for testing moderated mediation models: competitors or backups? *Acta psychologica sinica*. 2014 May. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.