RESEARCH ON THE INFLUENCE MECHANISM OF GREEN FINANCE AND REGIONAL ECONOMIC DEVELOPMENT BASED ON THE PERSPECTIVE OF TECHNOLOGICAL INNOVATION

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RESEARCH ON THE INFLUENCE MECHANISM OF GREEN FINANCE AND REGIONAL ECONOMIC DEVELOPMENT BASED ON THE PERSPECTIVE OF TECHNOLOGICAL INNOVATION

ADING LI

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BY

ADING LI

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Amidst global endeavors to foster sustainable and high-quality economic development, this research examines the influence of green finance on regional economic expansion from the perspective of technological innovation. This research employs panel data collected from 30 provinces in China spanning the years 2008 to 2021., developing a green finance development index and applying fixed-effects, mediation, and moderated mediation models to scrutinize the underlying mechanisms. Findings reveal that green finance substantially advances regional high-quality economic growth, with regional innovation capacity. Moreover, environmental pollution control's intensity improves the beneficial effects of green finance by intensifying the mediating role of regional innovation capacity. However, green finance's effect displays regional heterogeneity, with more developed areas reaping greater benefits due to their superior financial infrastructure and innovation ecosystems. This research proposes specific suggestions for policy improvements, including the improvement of green finance policies, the expansion of green financial tools, the increase in research and development funding, and the implementation of tailored financial support strategies for specific regions. These contributions enhance the theoretical comprehension of green finance's function in economic development and provide actionable guidance for policymakers.

Keyword : Green finance, Regional Economic Growth, Regional Innovation Capacity, Environmental Pollution Control, Sustainable Development

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CHAPTER 1
INTRODUCTION

1.1 Background

Since the 21st century, global warming, ecosystem degradation, and environmental pollution have converged into a compound crisis threatening human survival (Stern, 2008) . As highlighted by the United Nations' environmental agency, environmental deterioration causes annual economic losses equivalent to 4.7% of global GDP. Against this backdrop, the notion of sustainable development has transitioned from a theoretical construct in "Our Common Future" to tangible international accords such as the Paris Agreement, with its core objective centered on resolving the "Jevons Paradox" of balancing economic growth and environmental depletion. The global transition highlights the pressing demand for innovative financial mechanisms capable of harmonizing economic growth with ecological conservation—a challenge that has grown increasingly vital as climate change accelerates and resource scarcity intensifies.

As the largest developing economy globally, China elevated the present state of environmentally focused financial mechanisms to a national strategic instrument by introducing the "Guidelines for Establishing a Green Financial System" during the 2016 G20 Hangzhou Summit (Kirton & Wang, 2023). By the close of 2023, the green credit balance in China had reached 27.2 trillion yuan, indicating a year-on-year increase of 31.7% and substantially exceeding global averages. This institutional innovation demonstrates that green finance has transcended the profit-driven constraints of traditional finance, assuming dual responsibilities for fostering sustainable and efficient economic expansion and facilitating sustainable environmental transformation (Huang et al., 2023).China's rapid expansion of green finance demonstrates its strong commitment to sustainable development, as well as its acknowledgment of the critical role financial systems play in facilitating both environmental and economic transitions. Nevertheless, the success of green finance in achieving these dual goals depends heavily on its

capacity to foster innovation and efficiently allocate resources across varied regional landscapes.

Given green finance shows potential to boost economic advancement is widely acknowledged, its underlying mechanisms remain underexplored. Existing studies predominantly focus on its direct environmental impacts, such as pollutant reduction and energy efficiency enhancement (Muganyi et al., 2021). However, limited attention has been paid to how green finance promotes regional economic development through technological innovation—a core driver of economic progress. Green finance can catalyze green technology R&D and application by funding innovation activities and optimizing resource allocation, thereby stimulating regional economic growth. This innovation-driven approach holds particular significance within the framework of China's ambitious carbon neutrality and sustainable development objectives, as technological progress is indispensable for separating economic growth from environmental harm.

Furthermore, regional economic disparities represent a defining characteristic of China's development trajectory. Significant variations in the context of economic development stages, financial system maturation, and environmental guidelines across regions suggest heterogeneous effects of green finance (Lv et al., 2021). Empirical evidence indicates that highly developed areas characterized by mature financial systems and dynamic innovation networks can more efficiently utilize green finance to drive technological progress and economic expansion. Conversely, underdeveloped regions constrained by financial resource scarcity and innovation deficits may face limitations in leveraging green finance. Thus, investigating the pathways through which green finance influences economic growth across diverse regional contexts—particularly the intermediary function of technological advancement and the regulatory influence of environmental policies—holds critical theoretical and practical significance. Grasping these regional disparities is crucial for crafting targeted policies that enhance the effectiveness of green finance and foster balanced zonal advancement.

Based on the aforementioned background and research questions, this research seeks to formulate a comprehensive analytical system to examine the impact of green finance on regional economic growth, grounded in theoretical analysis. Specifically, the significance of this research is reflected in manifested in several key areas: Firstly, this study innovatively constructs a transmission mechanism of "green finance—regional innovation capacity—high-quality economic growth." Unlike Muganyi et al. (2021), who focus on the environmental benefits of green finance (e.g., pollutant reduction), this paper systematically reveals how green finance fosters economic growth by targeting backing of eco-friendly technology innovation efforts and optimizing the allocation of innovation resources, thereby deepening the understanding of the economic functions of green finance. Second, this research expands the analysis of the moderating role of environmental governance intensity. In contrast to Huang et al. (2023), who focus solely on the single dimension of green finance, this research employs the moderated mediation framework to demonstrate that a one-unit increase in environmental governance intensity boosts the value-added effects of green financial mechanisms on innovation performance at the regional level by 6.3%, thereby amplifying its indirect impact on economic growth. This finding provides a new perspective for policy optimization under the "dual carbon" goals. Third, this research explores the variations across different regions of green finance's impact. Unlike the descriptive analysis of regional disparities by Lv et al. (2021), this paper quantifies the pathways through which green finance operates in different regions using subsample regression models. The identified 1.5-fold marginal efficacy disparity between eastern (0.196) and western (0.128) regions, a difference attributed to the gradient gap in financial infrastructure and innovation ecosystems. This provides empirical evidence for formulating differentiated green finance policies. Finally, based on the "efficiency ladder" characteristics revealed by the empirical analysis, this study proposes targeted policy optimization recommendations. For the eastern region, it suggests strengthening

innovations in green securities and carbon finance instruments, while for he nation's central and western territories, a policy combination of "fiscal interest subsidies + technology transfer" is recommended. This approach breaks away from the traditional "one-size-fits-all" model and provides an operational framework for balanced regional development.

In summary, through mechanism innovation, methodological expansion, and policy optimization, this research expands the theoretical underpinnings of green finance and provides pragmatic guidance for fostering high-quality economic growth and green transformation. By clarifying the role of regional innovation capacity as a pivotal mediator and environmental governance intensity as a significant moderator, this research contributes to the scholarly discussion surrounding green finance while providing actionable insights for decision-makers aiming to leverage green finance for sustainable development.

The structure of this research is organized as follows: Chapter 2 reviews the existing literature and develops theoretical hypotheses based on the reviewed studies. Chapter 3 describes the sources of data and the methods used for research employed in the study. Chapter 4 offers the empirical outcomes, focusing on green finance operates to achieve impacts economic growth. Chapter 5 wraps up the research by highlighting major results, examining their significance, and proposing targeted policy directions, along with potential directions for future research.

1.2 Objective of The Research

This research seeks to design detailed below (As illustrated in the figure 1):

(1) To validate the direct influence of green finance on sustainable regional economic growth.

(2) To explore the mediating mechanism of regional innovation capacity.

(3) To determine the moderating function of environmental pollution control intensity.

(4) To investigate the discrepancies in the effects of green finance across different regions.

(5) To propose policy proposals for enhancing the effectiveness of green finance.

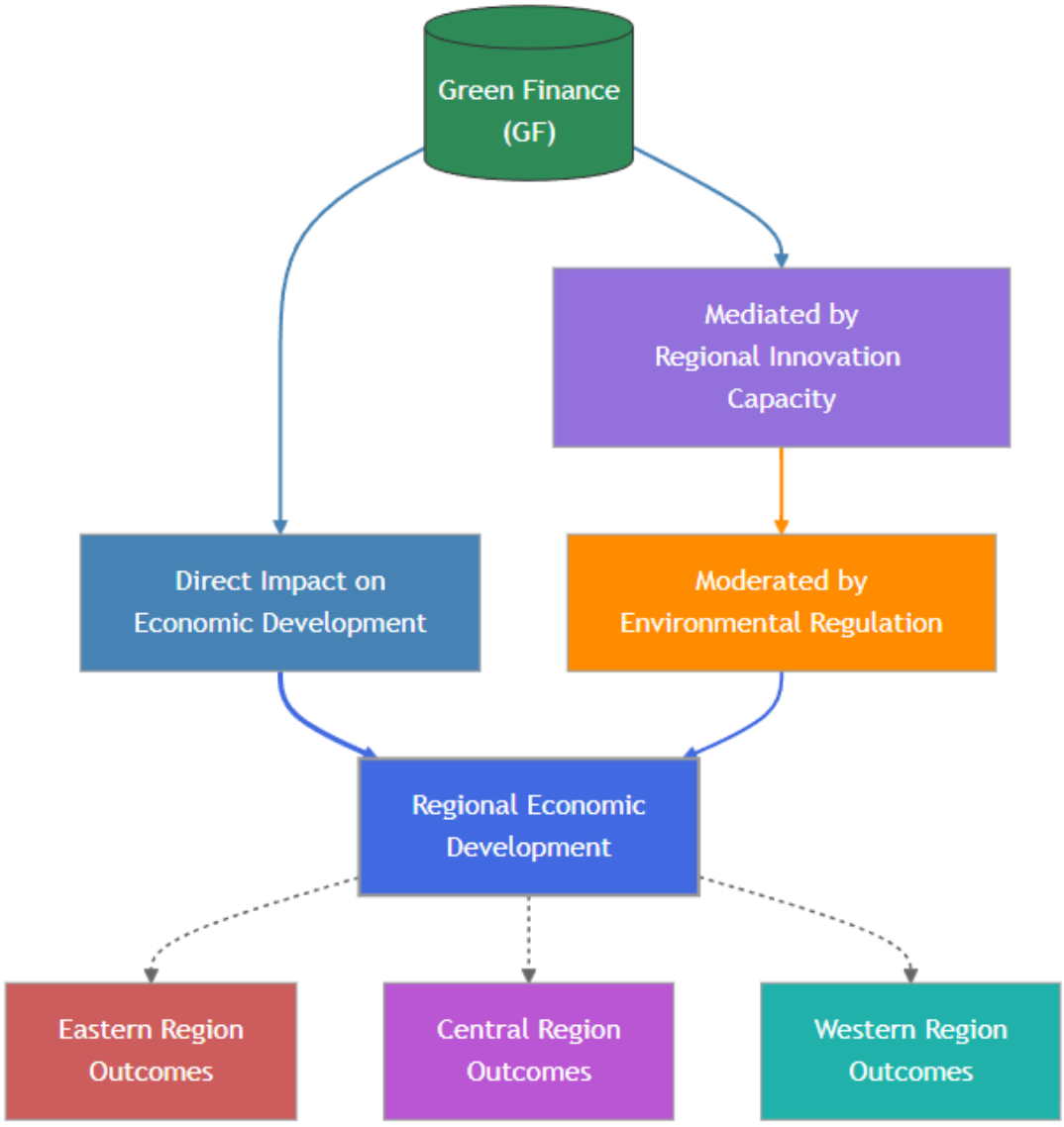

Figure 1 Research Objective

1.3 Significance of the Research

The significance of this study lies in its multifaceted contributions to encompassing theoretical advancements and real-world applications in the realm of green finance and local economic growth. Firstly, from a theoretical perspective, this

research innovatively constructs a comprehensive transmission mechanism that elucidates how green finance influences high-caliber local economic growth through the mediating role of regional innovation capacity. This mechanism deepens the comprehension of the economic roles of green finance and extends the published studies on the interplay between financial instruments and sustainable economic growth. By incorporating the moderating effect of environmental pollution control intensity, the study offers a novel framework for analyzing the complex dynamics between green finance, innovation, and economic development under varying regulatory environments.

Secondly, the empirical analysis conducted in this study provides robust evidence on the regional heterogeneity of green finance's impact, which is essential for developing targeted and efficient strategies. The findings reveal that the influence of green finance varies significantly among diverse regions, stressing the requirement for regionally adapted strategies to maximize the benefits of green finance policies. This insight is particularly valuable for policymakers aiming to address regional disparities and promote balanced economic development.

Thirdly, the study's methodological rigor and comprehensive data analysis enhance the reliability and generalizability of the findings. By employing a combination of models with fixed effects, mediation analysis, and models of moderated mediation, the research offers a thorough and systematic examination of the underlying mechanisms. This method ensures the reliability of the findings provides a firm underpinning for future research to build upon.

Finally, the policy recommendations derived from this study offer actionable guidance for optimizing green finance policies and enhancing their effectiveness in promoting sustainable economic growth. These recommendations are customized for address exact requirements along with challenges of several regions, thereby contributing to the development of more inclusive and sustainable economic policies. Overall, research is highly impactful advances the interpretation of green finance's

position in local economic growth and offers important perspectives for policymakers, professionals, and scholars.

1.4 Advantage of The Research

The potential innovations of this research can be summarized in three aspects: theoretical perspective, study focus, and study framework.

First, considering the research angle, this research examines the influences mechanism of green finance on high-quality regional economic growth, conducting an in-depth investigation through the lens of technological innovation. Due to the increasing global attention to sustainable development, high-quality regional economic development requires not only innovation-driven growth but also a situation of mutual gain that promotes fiscal and environmental sustainability. Against this backdrop, an increasing number of studies have explored the determinants of green innovation from perspectives particularly tiers of socioeconomic progress, industrial structure adjustment, and government fiscal expenditure. However, research from the standpoint regarding green finance remains relatively scarce. Although some scholars have examined the correlation between green finance and green innovation, the empirical results exhibit a lack of consistency and even show significant differences, with few studies deeply revealing the intrinsic relationship between the two. This study argues that finance is the core of the modern economy and the lifeblood of the real economy. China's current and future efforts to attain the objectives of reaching a carbon peak by the year 2030 and achieving carbon neutrality by 2060 require substantial green investment and financing. Green finance has great potential but also faces unprecedented challenges. Grounded in this reality-oriented perspective, this study examines the financial drivers of high-caliber local economic growth through the distinctive perspective of green finance, thereby addressing a notable lacuna in the published scholarship.

Second, in terms of research content, this study systematically investigates the contribution of green finance on the advancement of high-quality regional economic development through a combination of theoretical modeling and empirical analysis. Current academic research on the impact of green finance on high-quality regional economic development is mostly descriptive and normative, with few studies systematically clarifying the intrinsic logic between the two. To address this gap, this study innovates by combining rigorous theoretical modeling with scientific empirical analysis to examine the causal effects and mechanisms through which green finance influences high-quality regional economic development. Specifically, within the theoretical modeling part, my research constructs a multi-sector model based on sustainable development theory, externality theory, and endogenous growth theory, which includes government policy, market environment, and financial intermediaries, and rigorously analyzes the intrinsic relationships between green finance, technological innovation, and economic growth. In the empirical analysis part, analysis utilizes cross-sectional time-series data encompassing 30 in China, with observational window from 2008 to 2021 and employs multiple models how green finance drives the advancement of high-caliber local economic growth, analyzed from a macroeconomic standpoint.

Third, with respect to research design, this study elucidates the inherent logical connection between green finance and the advancement of high-caliber local economic growth through rigorous mathematical derivation and applies various econometric methods to scientifically identify the true relationship between the two. Existing literature examining the sway of green finance on the advancement of high-caliber local growth in the economy frequently exhibits shortcomings in oversimplified model settings, single indicator selection, and failure to effectively address endogeneity issues. This study innovates in research design by using rigorous and scientific theoretical and empirical research methods to provide credible evidence for examining the true intrinsic relationship between the two. Specifically, in the theoretical modeling analysis part, this

study assembles a multi-sector model based on sustainable development theory, externality theory, and endogenous growth theory, and analyzes the dynamic relationships among green finance, technological advancement, and economic growth through mathematical derivation. In the empirical analysis part, to mitigate estimation biases that may arise from reverse causality and omitted variable bias, and other possible explanations, this study employs high-dimensional fixed-effects models and combines robustness and sensitivity analyses to guarantee the validity of the research findings.

1.5 Scope of the Research

1.5.1 Research Population

The sample population for this research encompasses all provincial-level administrative regions in mainland China. Specifically, the study targets economic, financial, and technological data from 30 provinces (11 in the east, 8 in the centre, and 11 in the west), autonomous regions, and municipalities over the period 2008–2021. Tibet, Taiwan, Hong Kong, and Macao are excluded given the panel's inherent attrition incompleteness. The rationale behind this selection is to ensure data availability, consistency, and quality, thereby increasing the scientific trustworthiness of the outcomes. The population is intended to capture the broad landscape of regional economic development, green finance initiatives, and technological innovation activities across diverse administrative and economic settings in China.

1.5.2 Research Sample

The research sample comprises thirty provinces, autonomous regions, and municipalities are located within mainland China, selected based on the availability and completeness of data on green finance, regional economic development, and technological innovation. The sample is classified into three regions—eastern, central, and western (As shown in figure 2)—according to geographical and economic characteristics. This stratification enables the study to analyze regional heterogeneity in

the implementation and effectiveness of green finance policies. Provinces in the eastern area serve as leaders in economic output and financial innovation, those located in the middle of region are key in industrial transformation, and those in the western region are critical for resource-based green development. This representative and balanced sample facilitates a thorough examination of the differentiated impacts of green finance across varied developmental contexts.

Figure 2 China's Provincial and Regional Breakdown

1.6 Definition Terms

Green finance refers to financial activities that support environmental protection, climate change mitigation, and sustainable development. It covers a variety of financial tools, including green credit, green bonds, and green insurance, and green investment funds. This research, involves the formulation of the Green Finance Development Index

(GFDI) utilizing the entropy method, aimed at providing a thorough assessment of the advancement of green finance in various regions.

High-quality economic development is a multidimensional perception that encompasses economic advancement, innovation, nature-related sustainability, and equitable social outcomes. In this study, the High-Quality Economic Development Index (HQEDI) is used as a proxy for regional economic development.

Regional innovation capacity pertains to the competence of a region to generate, attract, and utilize technological innovations to drive economic growth. It is measured through a composite index that includes indicators such as R&D investment intensity, patent applications, and technology transaction activity. In this study, the Regional Innovation Capacity Index (RIC) serves as a mediating variable.

Environmental pollution control intensity measures efforts and resources allocated by a region to manage and reduce environmental pollution. It is typically indicated by the share of funds designated for managing pollution of the environment relative to the region's Gross Domestic Product. In this study, EP is used as a moderating variable.

1.7 Conceptual framework

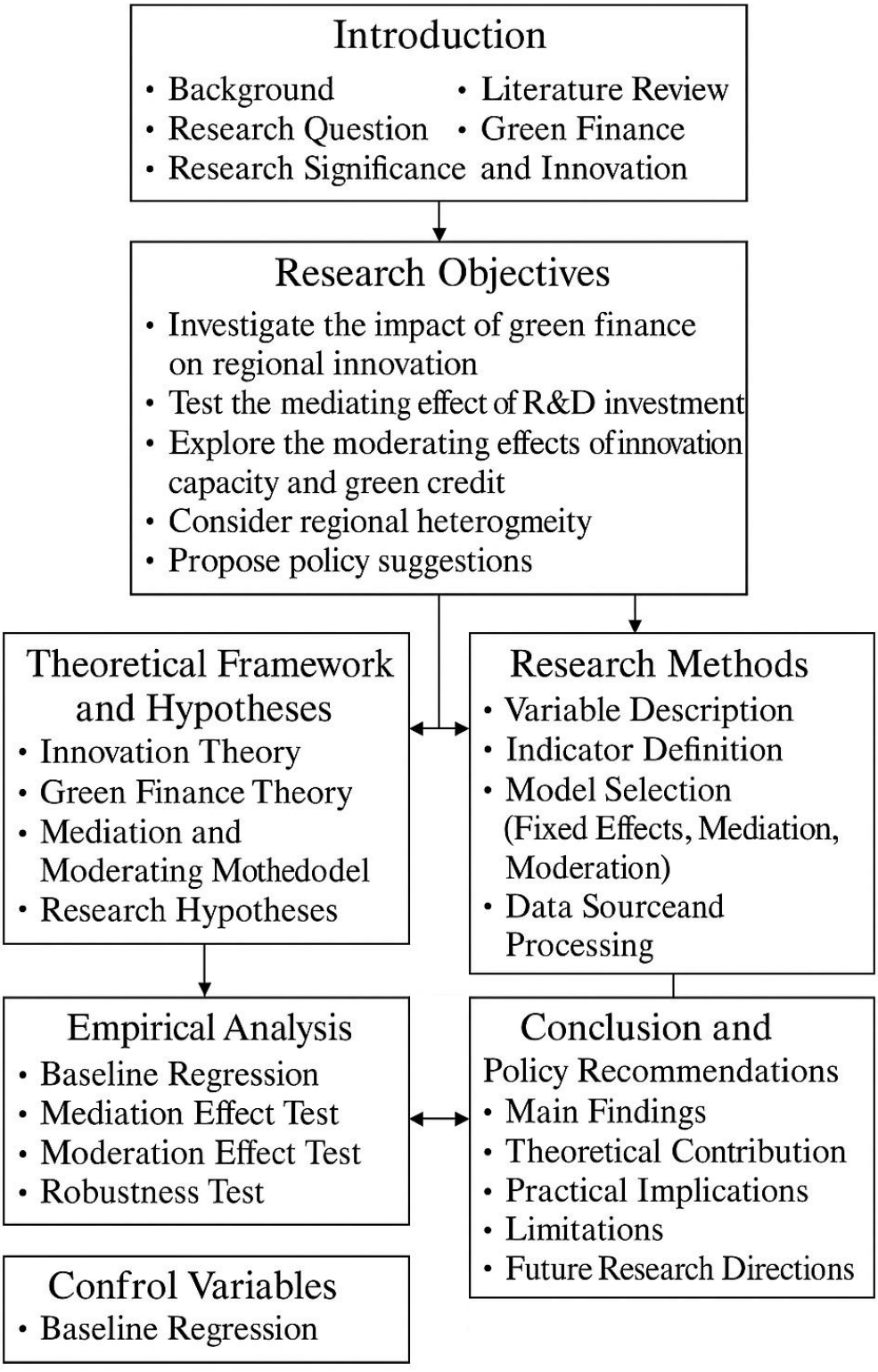

Figure 3 Research Framework Diagram

1.7.1 Mechanism Analysis

Green finance, as an essential financial tool for achieving eco-friendly progress and high-quality economic growth, operates through complex mechanisms. On one hand, it provides direct funding for environmentally friendly industries, thereby promoting the advancement of these sectors. From another perspective, its influence extends to indirect pathways, such as stimulating technological innovation, optimizing the efficiency of resource allocation, and enhancing environmental governance, all of which have profound implications for regional economic development. Drawing on the theories of technological innovation, the resource-based view, and innovation diffusion, this study constructs a mediating mechanism framework of "green finance—technological innovation capacity—high-quality economic development", additionally, the study incorporates further introduces the intensity of environmental pollution control as a moderating indicator to delve into the heterogeneity of the effects of sustainable finance.

Specifically, green finance employs financial instruments to direct capital towards environmentally friendly and low-carbon sectors. This effectively relieves the financial limitations encountered by businesses during their green transition, enhances the efficiency of capital allocation, and thereby encourages companies to boost their investment in green technology investigation and innovation. According to the resource-based view (RBV), the innovative capacity of enterprises originates from their scarce and non-imitable internal resources and capabilities (Wernerfelt, 1984). The involvement of green finance provides enterprises with the possibility of acquiring technological innovation resources to a certain extent, thereby contributing to the enhancement of the overall the technological inventive ability within the region. Technological innovation serves as the fundamental catalyst for the advancement of regional economic development, can drive industrial upgrading and economic structural optimization through new products, new processes, coupled with new

industrial chains, ultimately leading to improvements in the quality and efficiency of the economy. Therefore, the impact of green finance on regional economic development is not only direct but also indirect through the enhancement of regional technological innovation capacity.

Moreover, environmental regulation serves as a significant "institutional incentive" within the advancement of sustainable finance technological innovation and economic progress. The innovation diffusion theory(IDT) indicates that the institutional setting is essential in the pathways and intensity of innovation diffusion (Dearing & Cox, 2018). The degree of rigor in environmental pollution control serves as a significant indicator of the effectiveness of regional environmental policy implementation, can form external constraints and incentive mechanisms for green investment, thereby further improving the efficiency of green finance utilization of resources. When the rigor of environmental regulation is elevated, green finance is more likely to flow towards projects with high technological content and low emissions, consequently, this reinforces the motivational influence of sustainable finance on the progress of innovative capabilities and amplifies its indirect effects on sustainable finance on economic development by means of technological innovation. Therefore, the strength of environmental pollution control assumes a considerable adjusting function in the pathway of “green finance—technological innovation—economic development.”

1.7.2 Research Hypotheses

Drawing from the aforementioned theoretical framework, this research presents the subsequent research hypotheses:

H1: Green finance (GF) significantly promotes high-quality economic development (EH) in the region.

H2: Green finance (GF) suggests in a subtle way high-quality economic development (EH) in the region by enhancing the ability of a region to foster innovation (RIC), that is, it plays a mediating role.

H3: The intensity of environmental pollution control (EP) moderates the nexus between green finance and innovation capacity at the regional level (RIC), thereby affecting the indirect contribution of green finance on high-quality economic development through technological innovation, that is, there is a moderated mediating effect.

To elucidate the theoretical logic and mechanism of action of this study more clearly, Figure 4 presents a research framework model illustrating the influence of sustainable finance on the advancement of high-standard regional economic advancement. This framework explicitly reveals the immediate impacts of green finance (GF) on the advancement of high-quality regional economic development (EH), coupled with the non-direct consequences mediated through the enhancement of regional innovation capacity (RIC). Additionally, the model incorporates the intensity of environmental pollution control (EP) as a moderating variable to further analyze its regulatory effects within the pathways of green finance's influence.

The degree of rigor applied to environmental pollution control measures is expected to exert a direct influence on the capacity for innovation within a given region and may also modulate the promotional impact of environmentally sustainable finance on technological ability to innovate through its interaction term with green finance (GF×EP), thereby influencing the indirect influence of green finance on economic development mediated by innovation.

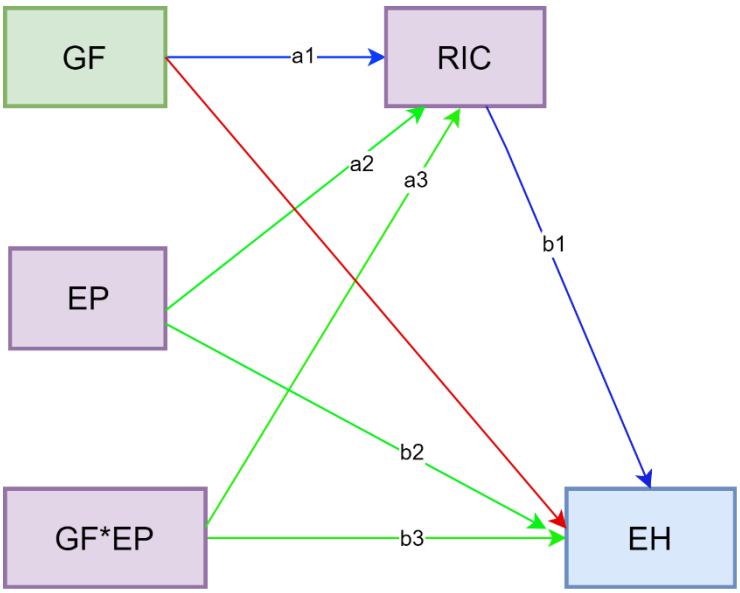

Figure 4 Impact mechanism pathway diagram

CHAPTER 2
LITERATURE REVIEW

2.1 Theory of Sustainable Development and Environmental Dynamic Model

2.1.1 Theory of Sustainable Development

Amid escalating issues like population growth, depletion of natural assets, and degradation of natural ecosystems, promoting sustainable socio-economic development has become an imperative for achieving unity humanity and environment. The theory of development that meets present and future needs posits that advancement of the economy should meet the expectations of the current era without compromising the ability of future generations to meet their own needs. This concept was first formally articulated in the 1987 report *Our Common Future* (Keeble, 1988), which provided the scientific definition of green growth: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

This led to the international community has continuously advanced the application of sustainable development principles in policy and practice. In 2015, the United Nations approved the *2030 Agenda for Sustainable Development (Lee et al., 2016)*, which further delineated 17 specific goals for coordinated progress in economic, social, and environmental dimensions. These goals underscore the central role of environmental protection, resource efficiency, and green transformation in sustainable development.

As an essential element of eco-development, green finance seeks to support environmentally friendly and resource-efficient economic activities through financial mechanisms. By channeling capital toward green industries, sustainable finance fosters economic growth along with enables mitigate environmental pollution and alleviate resource scarcity. Within the framework of regional economic growth, green finance facilitates structural transformation, industrial upgrading, and high-quality growth through capital provision, risk management, and policy incentives. Consequently, green

finance has emerged as a key driver of sustainable regional development, offering robust support for achieving a win-win scenario between economic prosperity and ecological sustainability.

2.1.2 Environmental Dynamic Model

Economies face environmental constraints that make balancing economic growth with environmental protection a central issue. According to classical models in environmental economics, the environmental level E serves as a key variable in economic activities: it influences both residents' utility and production on one hand, while being degraded by resource extraction activities on the other. In this model, the dynamic changes in the environment are represented by the following equation:

$$\dot{E} = \vartheta E(E_0 - E) - P(N,H) = Z(E,N,KH), \quad (0 < E < E_0) \qquad 2.1$$

Here, E represents the environmental quality variable, and $\dot{E}$ denotes the rate of change in environmental quality over time. This rate is determined by the environment's self-restoration capacity $\vartheta E(E_0 - E)$ and pollution P .The self-restoration capacity depends on the deviation between the current environmental level E and its initial state E_0. Resource extraction N is utilized for production, but such extraction damages the environment and generates pollution. The pollution emission function is assumed to be $P = N/H$, where H represents the emission-reduction technology level, indicating that higher levels of such technology lead to lower pollution per unit of resource extraction.

In real-world economic activities, many socially essential industries—such as steel, petroleum, and coal—are difficult to fully replace. Therefore, reducing pollution by improving emission-reduction technologies holds greater practical significance. In this context, green finance plays a crucial role by providing financial support for the

research, development, and deployment of these technologies. This approach not only enhances environmental restoration capacity and reduces pollution levels but also facilitates the achievement of sustainable and robust economic advancement.

The theory of sustainable development is primarily manifested in three aspects (As shown in figure 5): First, through capital allocation and policy incentives, green finance directs social capital toward environmental technologies and green industries, reducing economic growth's dependence on natural resources and thereby enhancing the environment's self-restoration capacity. Second, by promoting the enhancement of investments in research and development of environmental technologies by enterprises, green finance improves emission-reduction technology levels (H), lowers the pollution intensity of resource extraction activities, and facilitates the green transformation of economic activities. Third, leveraging financial instruments supports regional economies in transitioning toward efficiency, cleanliness, and low-carbon development, achieving a win-win scenario for both economic and environmental benefits.

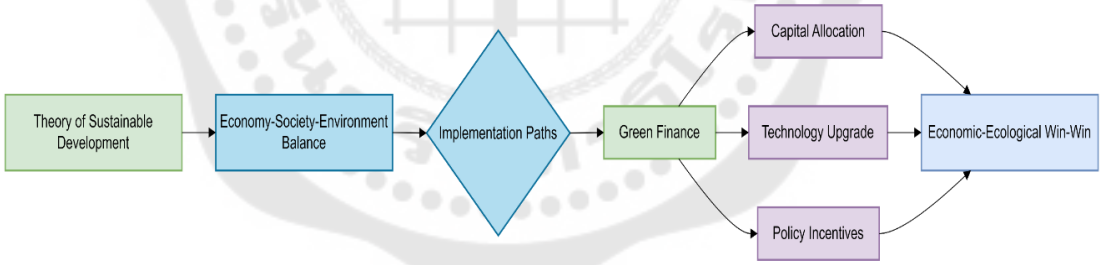

Figure 5 Sustainable Development Theory

2.2 Theory of Externalities and Capital Allocation Equilibrium Model

2.2.1 Theory of Externalities

The theory of externalities originated in the late 19th century, with Marshall first introducing the concept of external economies in Principles of Economics. He posited that a firm's external environment (e.g., market expansion, improved location, transportation accessibility) could reduce production costs and increase profits. However, this perspective primarily focused on the positive impacts of external

environments on firm production.

Pigou formally established the concept of economic externalities in his 1920 work The Economics of Welfare, arguing that when social marginal costs (benefits) diverge from private marginal costs (benefits) in production, positive or negative economic externalities emerge. This marked the formal establishment of externality theory.

In the context of green finance, externality issues become particularly salient. On one hand, green finance policies theoretically generate positive externalities by using market incentives to guide firms toward green innovation and low-carbon transition. Such policies not only drive technological innovation but also enhance social welfare through environmental improvements. For instance, when green credit supports green technology R&D, even if individual firms cannot capture all the benefits of innovation, society as a whole reaps the rewards of technology diffusion.

On the other hand, traditional firms pursuing profit maximization often neglect the negative externalities of production activities, such as carbon emissions and pollution. Green finance policies address this by internalizing external costs through pollution taxes, green investment subsidies, and other instruments to promote efficient resource allocation.

Coase's 1960 work The Problem of Social Cost argued that externality issues stem from ill-defined property rights rather than market failure. The Coase Theorem suggests that with zero transaction costs and well-defined property rights, market participants can negotiate externality solutions to achieve optimal resource allocation. For green finance, clearly defining environmental ownership rights and establishing driven by market forces trading mechanisms is able to effectively mitigate externality problems. The carbon emissions trading system exemplifies this approach by creating tradable pollution rights that align environmental and economic objectives.

Thus, in green finance-driven regional development, externality theory explains

how policy instruments influence capital allocation between green innovation and traditional production sectors through incentive mechanisms and property rights definition, ultimately facilitating regional green transition. The theory provides critical insights for designing market-compatible green finance mechanisms that harmonizes economic development with ecological preservation.

2.2.2 Capital Allocation Equilibrium Model

To systematically illustrate how green finance policies influence the allocation of capital toward green innovation through market mechanisms, this paper builds a capital allocation equilibrium model grounded in externality theory. By integrating both capital market equilibrium and product market equilibrium, the model reveals the internal mechanism through which green finance advocates for the eco-friendly transition of regional economies. The fundamental equilibrium condition can be expressed as:

$$\varepsilon R_H = \varepsilon p_H H'(K_H) = R_Y = F'(K_Y) \qquad 2.2$$

where R_H represents the marginal return on capital in the green technology sector, influenced by the strength of environmentally sustainable financial assistance ε and the cost associated with environmentally friendly products p_H; $H'(K_H)$ is the marginal product of capital in the green sector; R_Y denotes the marginal return on capital in traditional sectors, and $F'(K_Y)$ is the output generated by an additional unit of capital in the traditional sector. The proposed framework reflects how green finance alters the marginal return structure of capital, thereby directing resources from traditional high-pollution industries toward green innovation sectors, and establishing a new market equilibrium.

Further, by introducing the capital allocation ratio $\eta \in$ (0,1), which denotes the proportion of total capital K allocated to the green sector (with $1-\eta$ allocated to the traditional sector), and accounting for technological heterogeneity and internalized

externalities, the capital allocation equilibrium can be written as:

$$\eta^{\mu+1}(1-\eta)^{1-\alpha} = \epsilon p_P \mu \alpha A_h A E^{\delta} N^{\beta-1} K^{\alpha+\mu} \qquad 2.3$$

where μ and α represent the output elasticity of capital in the green and traditional sectors, respectively; A_h is the technological efficiency of the green sector; A is the overall level of technology; p_P is the pollution tax, indicating environmental regulation intensity; E is the level of pollutant emissions; δ is the elasticity of pollution impact on output; N denotes the level of resource consumption (e.g., energy or water); and β reflects the marginal impact of resource use on output. The left-hand side is an increasing function of η, while the right-hand side is an increasing function of green finance intensity and pollution tax, indicating that stronger green financial support or higher environmental tax rates will lead to a higher share of capital flowing into green innovation sectors.

Under the social planner's optimization framework, which seeks to maximize overall social welfare, the optimal capital allocation ratio is given by:

$$\eta^* = \frac{\beta\mu}{\beta\mu+\alpha} \qquad 2.4$$

Additionally, the optimal level of green finance policy support can be articulated as:

$$\epsilon^* = \frac{\beta Y_H}{p_P N} \qquad 2.5$$

where Y_H is the output of the green segment. This equation suggests that the optimal green finance policy is strongly associated with the output magnitude, pollution tax, along with resource consumption. When green output increases or resource

consumption declines, a stronger green finance policy is required. Conversely, when environmental regulations intensify (e.g., through higher pollution taxes), the green finance support intensity may be moderated to maintain investment efficiency—implying a complementary linkage between sustainable finance and environmental regulation.

In conclusion, this model demonstrates how green finance policies, by altering the marginal return structure of capital, can guide capital allocation toward green innovation, thereby this facilitates the advancement of sustainable transformation and the enhancement of the quality of development within regional economies.

2.3 Endogenous Growth Theory and Environmental Constraint Mechanism

2.3.1 Endogenous Growth Theory

To systematically analyze the mechanism by which green finance drives regional economic growth under the context of accelerating green transition, this study extends the classical endogenous growth framework by integrating environmental constraints and financial support mechanisms. The foundation of this theoretical framework lies in the endogenous growth perspective, emphasizing the function of innovation along with knowledge accumulation in sustaining long-term increase in economic activity. Fritsch (2017), in his groundbreaking research *The Theory of Economic Development*, first articulated the concept of “creative destruction,” arguing that innovation—defined as the novel combination of production factors—drives economic evolution. This comprises the production of new products, the deployment of innovative production techniques, the exploration of new markets and resources, and the restructuring of industries, all of which are propelled by entrepreneurial dynamism (Aghion et al., 2015). Although neoclassical growth models, such as that proposed by Solow (1956), recognize the importance of technological progress, they treat it as exogenous and thus fail to explain its origins or long-term impact. To address this limitation, Romer (1990) incorporated research and development (R&D) activities and knowledge spillovers into the growth model, thereby endogenizing technological

progress as the key engine of sustained growth.

However, under the evolving paradigm of green development, classical endogenous growth models do not sufficiently capture the dual roles of environmental constraints and financial instruments in shaping innovation dynamics. To address this, sustainable finance has established itself as a vital policy approach designed to synchronize economic progress with environmental conservation. By channeling capital toward ecologically sustainable technologies and initiatives aimed at reducing carbon emissions, green finance facilitates development of sustainable innovation, pollution reduction, and industrial upgrading—thus becoming a vital driver of regional green transformation.

2.3.2 Environmental Constraint Mechanism

To formalize this mechanism, we assume the existence of a green innovation sector that supplies green technologies and emission-reduction equipment to meet firms' demands in their transformation processes. The green innovation level H is modeled as follows:

$$H = \begin{cases} A_h K_H^{\mu} & \text{if } K_H > 0 \\ H_0 & \text{if } K_H = 0 \end{cases} \quad 2.6$$

where A_h denotes the productivity of green innovation; K_H represents the capital allocated to green innovation, and $\mu \in (0,1)$ captures the diminishing marginal returns of capital in the green innovation sector. H_0 reflects the baseline emission-reduction capability in the absence of new investment. This threshold structure captures the reality that green technology breakthroughs require a minimum investment scale—insufficient capital input merely maintains the status quo in pollution control.

Under the influence of green finance, firms can obtain funding through dedicated financial instruments (e.g., green credit, green bonds) to invest in emission-reduction technologies, especially when environmental taxes or carbon pricing are in

effect. This investment becomes economically attractive as it reduces tax burdens and improves production efficiency. Green finance thus reduces financing constraints, promotes R&D in green technologies, and enhances the innovation capacity A_h, ultimately accelerating regional economic growth along a sustainable path.

In sum, by embedding green finance into the endogenous growth model, this paper reveals how financial policy instruments reshape capital allocation and innovation incentives under environmental constraints. This extended model lays the groundwork theoretically for comprehending the significance of green finance in stimulating green innovation and achieving coordinated economic-environmental development on a regional scale.

2.4 Research Relates

The following are relevant studies on green finance and regional economic advancement:

Green finance now constitutes a focal point within the global financial system due to its pivotal role in promoting eco-friendly growth and tackling environmental issues. Throughout China, the advancement of green finance has been closely examined in various regions, concentrating primarily on the Yangtze River Delta. Researchers in this region have observed a positive correlation between the growth of regional GDP and the expansion of green finance (Xie et al., 2020). However, observed inequalities in the progress of regional green finance have also been highlighted, underscoring the necessity to bridge the regional divide in China (Lv et al., 2021). Green finance's role in regional economic advancement has been a focal point of interest, with research examining its impact on energy intensity and total factor productivity across various regions in China (G. Li et al., 2023; Lv et al., 2022). Findings indicate that green finance plays a positive role in enhancing agricultural green total factor productivity, despite regional variations and an inverted U-shaped effect. Additionally, the interplay between environmental regulation intensity, green finance, and environmental sustainability has

been explored, suggesting that the advancement of green finance greatly aids in fostering eco-conscious sustainability in China (Deng & Zhang, 2023). In Europe, the concept of regional bioeconomies has been associated with public finance processes and sustainable policy narratives, with case studies from Finland, Sweden, and Spain offering insights into the interplay between eco-friendly finance and sustainable growth (Albrecht et al., 2021). Furthermore, the effects of environmentally sustainable finance on promoting eco-friendly progress in the European Union have been investigated, highlighting the significance of spatial analysis in comprehending the outcomes driven by green finance on regional economies (Kwilinski et al., 2023).

The following are relevant studies on technological innovation and regional economic development

This study has undergone multidimensional theoretical expansion and empirical deepening. At the theoretical level, Howells (2005) pioneered the "cognitive framework theory," emphasizing that the selection of research perspectives is pivotal in analyzing the dynamic relationship between innovation and development. Building upon this foundation, "dual-helix support model" systematically illustrating how the enhancement of regional R&D competitiveness requires synergistic interactions between policy instruments and market mechanisms. Regarding theoretical breakthroughs in spatial innovation carriers, Yu and Jackson (2011) deconstructed the dimensions of regional innovation clusters (RICs), revealing the "triple paradox" inherent in their conceptualization process, thereby establishing a benchmark for subsequent research.

Empirical studies in the Chinese context demonstrate marked generational evolution. In the foundational phase, research focused on the direct effects of innovation inputs. For instance, Hui and Bei (2019) constructed a multiplier effect model using data from coastal cities, identifying a bidirectional reinforcement loop between patent increments and R&D investments. Recent studies have extended to innovation networks, with Jing et al. (2020) uncovering a radius threshold for university knowledge spillovers,

which exhibits a nonlinear correlation with regional industrial upgrading. Notably, in the policy dimension, Xia et al. (2019) proposed a "government-market dynamic equilibrium framework," offering a novel paradigm for optimizing innovation policies.

Methodological breakthroughs have emerged in spatiotemporal dynamics research. Yuan et al. (2022) applied a modified coupling coordination degree model, confirming that the synergistic development of high-tech industries and regional economies exhibits an "efficiency ladder" characteristic with significant spatial spillover effects. Wang (2023) employed a DID approach to demonstrate that green technological innovation enhances regional economic development quality by 23.6% through the mediating channel of industrial structure advancement.

The following are relevant studies on green finance and technological innovation

Extensive research has explored the influence of eco-friendly finance and innovation on sustainable growth. Notably, researches have emphasized that the inception of experimental areas for sustainability development has exacerbated regional disparities in the advancement of green initiatives (Wang et al., 2021), with financial investments in environmental protection playing a crucial role. Ding et al. (2022) emphasized that an innovative atmosphere enhances the efficiency of knowledge sharing within green finance R&D teams, thereby improving team performance. Yan et al. (2022) conducted an analysis that focused on the intermediary function played by sustainable finance and innovation. This role was specifically in relation to the influence of the acceptance of financial technology regarding the sustainable functionality of monetary organizations. Zhang et al. (2022) conducted a comprehensive study on the interactions between innovation, green finance, and the complex interplay of energy, environment, and climate factors. Their research underscored the critical importance of these dynamics for achieving sustainable development goals.

Y. Li et al. (2023) employed the Fuzzy Analytic Hierarchy Process (AHP) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) techniques to assess Environmental, Social, and Governance (ESG) components and policies in China's decisions regarding investments in green finance, recommending a focus on key ESG factors to enhance sustainability and resilience. Sadiq (2023) revealed the latest trends in green finance and green innovation research through bibliometric analysis. Notably, Wu and Song (2024) emphasized the importance of ensuring accuracy and reliability when studying the importance of sustainable finance and innovation in sustainable development.

The current a collection of written works have thoroughly examined the functions of sustainable finance and technological innovation in regional economic development. Research on green finance emphasizes its contributions to sustainable growth and environmental improvement, a conclusion that has been widely validated in studies conducted in both China and European countries. However, the matter of imbalance development of green finance over various regions remains an area that requires further investigation.

In the area of technological advancement, significant progress has been made both theoretically and empirically, with a focus on analyzing mechanisms such as policy-market synergy, innovation clusters, and spatial spillover effects. Nevertheless, current body of work still lacks thorough examination of the interaction in relation to sustainable finance and innovation. Although recent studies have examined the joint impact of the two on sustainable development, research that systematically investigates their integrated mechanisms across institutional, technological, and market dimensions remains scarce.

Future research should focus on the pathways through which sustainable finance facilitates regional green transformation via technological innovation. In particular, the roles of mediating and moderating effects should be emphasized, and

emerging variables such as ESG (Environmental, Social, and Governance) performance and digital finance should be incorporated. This approach will contribute to enhancing the theoretical depth and practical value of green development models.

CHAPTER 3
METHODOLOGY

3.1 Data collection and sources

This study investigates the effect regarding China's sustainable finance policies regarding the ability of regions to innovate across a 14-year span from 2008 to 2021. The data was gathered from authoritative publications and reliable databases, like the China Statistical Yearbook, China Regional Innovation Capacity Evaluation Report, China Financial Statistics Yearbook, China Science and Technology Statistics Yearbook, CSMAR, CCEER. The study encompasses data collected from 30 provinces throughout mainland China, totaling 420 observations. This data selection was conducted in accordance with modeling specifications to ensure accuracy, representativeness, and dependability.

3.2 Variable Definition and Measurement

In this study, to clearly elucidate the meanings, types, and measurement methods of each variable, we classify the key variables into five categories: dependent variable, independent variable, control variables, mediating variables, and moderating variables. This classification helps systematically organize the relationships among variables and offers a clear framework for empirical analysis. Table 1 Description of Variables provides definitions and measurement methods for these variables, serving as a foundation for the subsequent analysis.

Building on this, a comprehensive understanding of both the variables and the reasoning for their inclusion is essential for accurately analyzing the phenomena and interpreting their interrelationships. The following sections will offer detailed descriptions of each category, outlining the role of the variable that depends on others as the study's central focus, the effect of the independent variable, the exclusionary function of control variables, the transmission mechanisms of mediating variables, and the conditional effects captured by moderating variables.

The subsequent sections will provide a comprehensive account of each indicator category to lay a solid foundation for empirical analysis. The variable that depends on other factors is the main focus of my research, reflecting the economic phenomena we aim to explain or predict. The independent variable represents the key factors we believe influence the dependent variable. Regulatory variables are used to exclude other drivers, ensuring the precision of the estimation results. Mediating variables reveal the underlying mechanisms or pathways through which the independent variable impacts the dependent variable. Moderating variables examine how the relationship between variables changes under different conditions.

By conducting a rigorous investigation of these variables, the research aims to bring to light how green finance stimulates regional economic development by affecting regional innovation capacity and to explore how the intensity of environmental pollution control moderates the strength of this relationship. This multidimensional analytical approach not only enhances the study's explanatory power but also provides a scientific foundation for developing appropriate policies.

Table 1 Description of variables

Variable Type	Variable Symbol	Variable Name	Variable Explanation	Units/Dimension
Dependent Variable	eh	High Quality Economic Development	Economic advancement index derived from the entropy weighting method of measurement	Dimensionless (0–1 range)
Independent variable	gf	Green Finance	Index obtained by weighting the three levels of indicators after normalisation	Dimensionless (0–1 range)

Table 1 (Continue)

Variable Type	Variable Symbol	Variable Name	Variable Explanation	Units/ Dimension
Mediating variable	ric	Regional Innovation Capacity	Calculated through the comprehensive computation of five primary indicators.	Dimensionle (0–100 range)
Moderating variable	epci	Environmental Pollution Control Intensity	Total Amount of Environmental Pollution Control/Gross Domestic Product	Percentage (%)
Control variables	ind	Industrial Structure	Added Value of Secondary Industry (billion yuan)/GDP	Percentage (%)
	gdppc	Per Capita GDP	GDP/ Population	Yuan (RMB)
	hep	Human Capital	Population with Higher Education/ Population	Percentage (%)
	gov	Government Intervention	Fiscal Environmental Protection Expenditure/ GDP	Percentage (%)
	open	Opening up	Total Trade Volume of Imports and Exports in the Region Relative to GDP	Percentage (%)
	rd	R & D Investment	Expenditure on Innovation and Experimental Research Funds / GDP	Percentage (%)

Source: Data collection by the researcher

3.2.1 Explained Variables

This research employs the High-Quality Economic Development Index (HQEDI) as a proxy for regional economic development. The index is constructed based on a comprehensive evaluation framework, designed to systematically and objectively assess the multidimensional characteristics of economic progress (Wu & Song, 2024). HQEDI integrates five core dimensions to reflect the overall level of high-quality economic development, as detailed below (As shown in figure 6):

1.Innovative Development (30%): Accounting for 30% of the index, innovative development draws attention to the fundamental role of innovation in fostering sustainable economic expansion. In the current global economic landscape, innovation is seen as a new engine for economic growth, crucial for enhancing regional competitiveness and accomplishing enduring sustainable progress (Khizar et al., 2024).

2.Coordinated Development (15%): With a weight of 15%, coordinated development emphasizes the importance of balanced regional development. This includes urban-rural coordination, regional balance, and the equilibrium of various aspects of economic and social development, aiming to promote social harmony and stability (Gai & Zhou, 2022).

3.Green Development (15%): Representing 15%, green development reflects a commitment to environmental sustainability. Under the guidance of eco-transformation concepts, the transformation of output expansion patterns towards more environmentally friendly and low-carbon directions is essential for achieving harmonious coexistence between humans and nature (Yang et al., 2024).

4.Open Development (30%): Open development, at 30%, underscores the pivotal role of transnational economic interdependence. As globalization deepens, the degree of openness of regional economies directly affects their competitiveness and influence in the global market (Yang et al., 2024).

5.Shared Development (10%): Shared development, allocated 10%, focuses on the equitable distribution of economic benefits (Gai & Zhou, 2022). Making certain that the fruits of economic growth are collectively held by all members of society is key to achieving social equity and long-term stability.

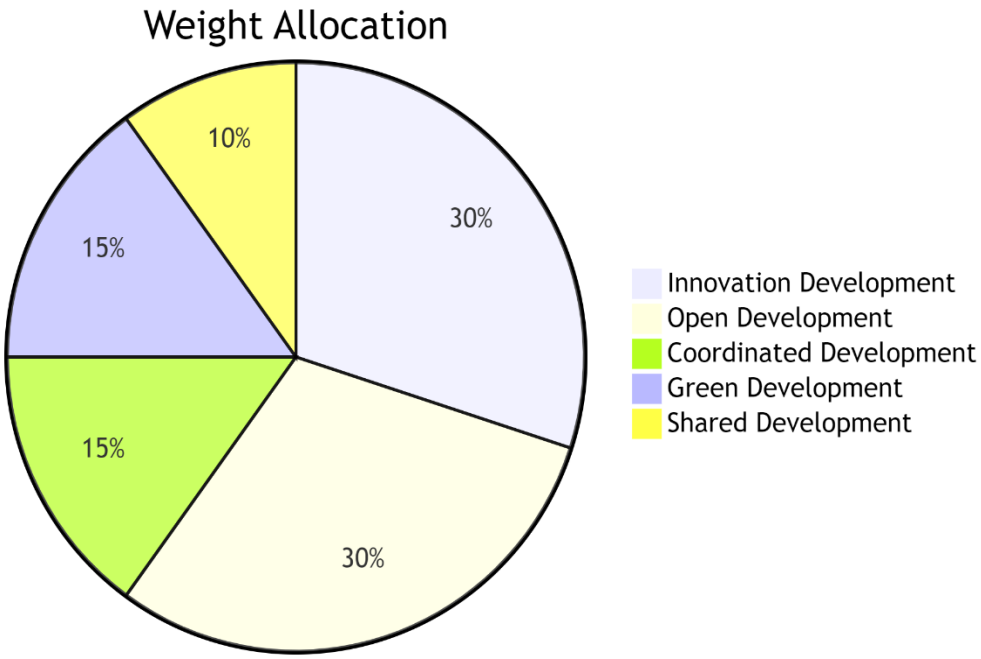

Figure 6 Five Core Dimensions & Weight Allocation of HQEDI

The weightings are determined through expert assessments, empirical analysis, and alignment with international frameworks, ensuring a comprehensive and balanced evaluation of top-notch economic growth. Table 2 details the composition of HQEDI and the allocation of weights for each dimension, providing a scientific and systematic tool for this research.

Table 2 High-quality economic development Index.

Level 1	Level 2	Level 3	Causality
High-quality economic development Index	Innovative development 30%	GDP Growth Rate	Positive
		R&D Investment Intensity	Positive
		Investment Efficiency	Negative
		Technology Transaction Activity	Positive
	Coordinated development 15%	Demand Configuration	Positive
		Urban and Rural Settlement Patterns	Positive
		Industrial Composition	Positive
		Sovereign Debt Burden	Negative
	Green development 15%	Coefficient of Elasticity of Energy Consumption	Negative
		Wastewater Per unit of Output	Negative
		Waste Gas Per unit of Output	Negative
	open development 30%t	Dependence on Foreign Trade	Positive
		Share of Foreign Investment	Positive
		Marketization Degree	Positive
	Shared development 10%	Share of Labor Compensation	Positive
		Sensitivity of Income Growth in the Population	Positive
		Urban-rural Spending Disparity	Negative
		Portion of Fiscal Outlay on people's livelihood	Positive

Source: Designed by the researcher

3.2.2 Explanatory Variables

The Green Finance Development Index (GFDI) is constructed using the entropy measurement approach, aiming to comprehensively and objectively evaluate the multidimensional characteristics. This index integrates four core dimensions. The distribution of weights for each dimension is based on scientific reasoning: green credit accounts for 50%, emphasizing the importance of distribution of funding in advancing eco-friendly growth (Volz, 2019). Green securities make up 25%, indicating advancements by institutions in the eco-friendly restructuring of capital markets (Meng et al., 2024). Green insurance makes up 15%, highlighting the important function of hazard management in overseeing environmental issues. (Surminski & Eldridge, 2017). Green investments make up 10%, reflecting the resource provisioning involved in real environmental policy administration (Geddes et al., 2018).

The weight allocation (As shown in figure 7) follows a rigorous academic rationale: first, it draws on cutting-edge research in green finance development, incorporating the latest theoretical advancements in academia (Dikau & Volz, 2021).Secondly, it adopts methodologies from global sustainable finance index construction to conform to international standards (Schoenmaker & Van Tilburg, 2016). Additionally, it utilizes the Delphi technique, combining expert evaluations with the marginal contributions of each field to green development, ensuring the scientific and systematic nature.

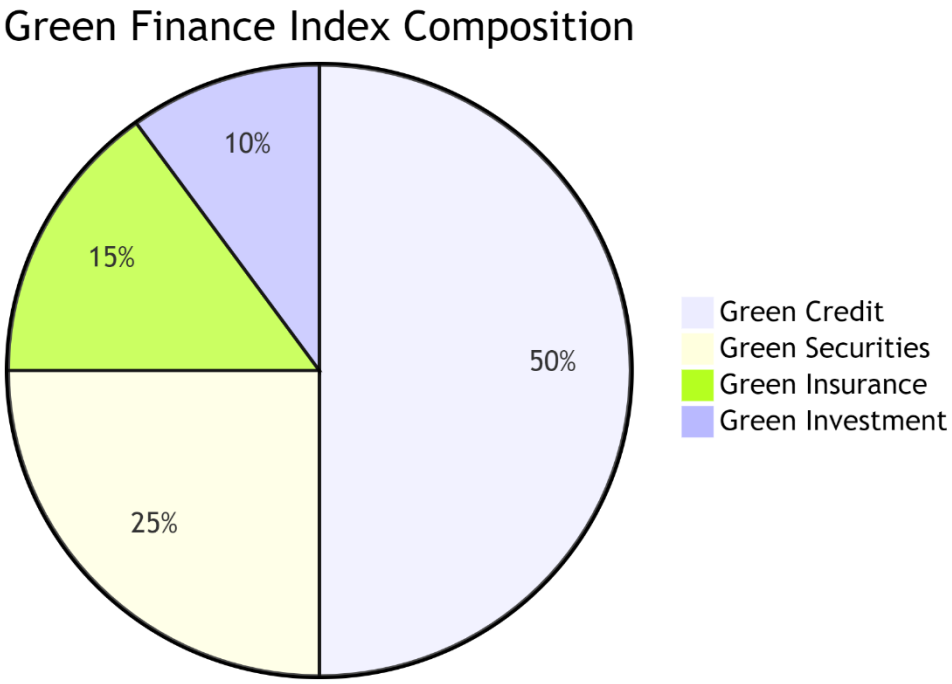

Figure 7 Four Core Dimensions & Weight Allocation of GFDI

Establishing the green finance index via the entropy value method. This approach produces an unbiased and thorough green finance development index, as outlined in Table 3. This index reflects the multifaceted aspects of green finance and serves as a strong explanatory variable for future empirical studies.

Table 3 Indicator System for the Development of the Green Finance Index.

Level 1	Level 2	Level 3	Causality
Green Finance Development Index (gf)	Green credit 50%	Fraction of interest expenditures within sectors with high energy use	Negative
		Percentage of recent bank credit extended to A-share listed companies in the environmental sector	Positive

Table 3 (Continue)

Level 1	Level 2	Level 3	Causality
Green Finance Development Index (gf)	Green securities 25%	Market capitalization of environmental companies listed on the A-share market	Positive
		Proportion of A-share value for A-share listed firms that have high energy consumption	Negative
	Green insurance 15 %	Expand the scope of insurance against environmental pollution	Positive
		Proportion of indemnification derived from insurance against environmental pollution	Positive
	Green investment 10%	Proportion of financial allocation directed towards the management of environmental pollution	Positive
		Proportion of public spending allocated to environmental protection initiatives	Positive

Source: Designed by the researcher

3.2.3 Control Variables

To conduct a thorough evaluation of the causes influencing regional development, the research includes the listed control factors: (1) The Industrial Structure (ind), based on the share of the marginal contribution of the secondary sector to Gross Domestic Product, expressed in billions of yuan, and is derived from the China Statistical Yearbook. This ratio not only quantifies the direct economic contribution of the secondary industry to regional GDP but also reveals its role in driving regional economic development (Tu et al., 2023).(2) Per Capita GDP (gdppc), acts as a measure of economic progress level and the standard of living within a region.(3) Human Capital

(hep): Captured by the population with higher education, it represents the educated workforce and is a crucial driver of regional development and innovation.(4) Government Intervention (gov): Proxied by the fiscal environmental protection expenditure as a percentage of Gross Domestic Product, it assesses the government's commitment to environmental protection and sustainable development.(5) Opening up (open): Gauged by the aggregate volume involving cross-border trade activities volume across the territorial unit expressed as a fraction of GDP, it reflects the magnitude of regional incorporation into the global economic system and the impact of international trade.(6) R&D Investment (rd): Represented by expenditure on research and development experimental funds expressed as a fraction of GDP, it shows the magnitude of investment in technical advancement and development. These factors, combined with a fixed-effects estimation approach that accounts for regional and time-related influences, improve the dependability of the findings.

3.2.4 Mediating and Moderating Variables

From the cross-perspective of Innovation Diffusion Theory (Dearing & Cox, 2018) and Theory Based on Resources (Wernerfelt, 1984), the RIC systematically quantifies the synergistic effects of regional innovation ecosystems through a five-dimensional indicator system encompassing knowledge creation, enterprise innovation, and innovation performance. Unlike traditional studies that focus on isolated innovation elements, the multidimensional integration mechanism of RIC not only captures the spatial gradient characteristics of knowledge spillovers along with reveals the structural constraints imposed by institutional environments and resource endowments on innovation performance. This framework supplies a complete analysis of the transmission the process by which sustainable finance drives productive capacity expansion via the reorganization of creativity drivers.

In terms of the moderation mechanism design, Environmental Pollution Control Intensity (EP) is introduced as a moderating variable. EP reflects the intensity of

environmental governance by measuring the compositional weight of a region's environmental remediation expenditures relative to its Gross Domestic Product. Studies have shown that a higher EP not only indicates a region's emphasis on environmental protection but also optimizes resource allocation and directs capital flows toward green projects, thereby enhancing the promoting effect of sustainable finance on regional economic development (Zhang et al., 2024). Consequently, EP plays a crucial moderating role, revealing the heterogeneous impacts of sustainable finance policies under different environmental governance intensities.

Furthermore, this study further explores how EP may influence the mediating role of RIC, that is, how EP might influence the pathway via which sustainable finance affects local economic development through regional innovation capacity. This analysis of moderating mediation effect helps to gain a deeper comprehension of the process by which sustainable finance operates under different environmental governance contexts and how policy interventions could optimize this mechanism. Through this multidimensional analysis, this study enriches the understanding of the mechanisms of green finance impacts and provides a scientific basis for developing more effective environmental and financial policies.

3.3 Empirical Model

This research utilizes a fixed effects model, a single mediation model, and a moderated mediation model to conduct a comprehensive analysis.

3.3.1 Multicollinearity Test Model

In order to enhance the robustness of the regression results, this research conducts tests and takes measures to address multicollinearity among independent variables. The multicollinearity condition occurs when the circumstance in which a set of predictor variables in a multivariate analysis framework are statistically associated. This can distort the estimation of coefficients and render statistical inferences unreliable.

Therefore, detecting and handling multicollinearity are crucial for accurate model specification and interpretation.

Specifically, this research uses the Variance Inflation Factor (VIF) to detect multicollinearity. The formula for VIF is as follows:

$$VIF_j = \frac{1}{1-R_j^2} \quad 3.1$$

Here, VIF_j represents the VIF for the *j*-th independent variable, and R_j^2 is the coefficient of determination obtained from regressing the *j*-th independent variable on all other independent variables in the model. Generally, a VIF When the value surpasses 10, it indicates substantial multicollinearity. Meanwhile, a tolerance value (the reciprocal of the VIF, Tolerance= $\frac{1}{VIF}$) below 0.1 also suggests severe multicollinearity.

Upon detecting multicollinearity, the following measures are taken to address it: First, each independent variable's theoretical and empirical relevance is carefully reviewed. If two variables are highly correlated and convey similar information, one of them will be removed from the model based on theoretical justification and the specific research context. Second, a composite variable may be created to combine the information from highly correlated variables, thereby reducing multicollinearity while retaining important information. Additionally, as an alternative approach, Principal Component Analysis (PCA) may be applied to transform the original correlated variables into a set of uncorrelated principal components, which are then used as new independent variables in the regression model. This technique helps to mitigate multicollinearity while preserving the variance explained by the original variables.

Through these tests and measures for multicollinearity, the study ensures that the derived coefficients in the regression model are reliable and interpretable. This reinforces the validity of the empirical findings and creates a sturdy base for accurately drawing conclusions about the relationships among the variables.

3.3.2 Fixed Effects Model

This research utilizes a fixed-effects approach, to address the potential influence. The choice of this framework builds upon the outcomes of the Hausman test, which indicate its appropriateness for the analysis. As a result, the model enables a more accurate assessment of the impact of green finance on regional economic development, thereby verifying Hypothesis 1. It is formulated as follows:

$$EH_{it} = \alpha_0 + \alpha_1 GF_{it} + \alpha_2 control_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.2$$

which EH_i represents regional economic development; GF_{it} represents green finance, and $control_{it}$ represents the control variables, the λ_i and μ_t denote the control variables pertaining to regional and temporal factors;ϵ_{it} denotes the stochastic error component.

This model setup helps to exclude factors that may influence regional economic development but are unrelated to green finance policies, such as inherent geographical conditions and historical backgrounds of regions. Through the fixed effects model, we can more clearly observe the actual impact of changes in sustainable investment mechanisms for growth, providing solid research-backed basis for interpreting the operational performance of green finance policies.

Furthermore, the fixed effects model also helps to reveal the heterogeneous impacts of green finance policies across various geographical areas, establishing a foundation for the development of differentiated place-based fiscal mechanisms. With this model, we can evaluate the effectiveness of green finance in promoting regional economic growth and identify which regions can benefit more from green finance policies.

3.3.3 Mediated Effects Model

To test Hypothesis 2, the research establishes a framework of recursive equations, utilizing the methodological approach proposed by Zhonglin and Baojuan (2014). This methodology facilitates an examination of the internal mechanisms that connect green finance to regional economic development, by assessing the effects of green finance on regional innovation capacity (RIC) (path a) together with the ensuing role of regional innovation capacity (RIC) on regional economic development (path b). The model is constructed in the following manner:

Path a: Impact of green finance (GF) on the intermediary parameter (RIC):

$$RIC_{it} = \delta_0 + \delta_1 GF_i + \delta_2 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.3$$

Path b: Effect RIC on regional economic development(EH):

$$EH_{it} = \varepsilon_0 + \varepsilon_1 RIC_{it} + \varepsilon_2 GF_i + \varepsilon_3 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.4$$

where RIC_{it} serves as the mediating variable. In alignment with the research trajectory established by Zhonglin and Baojuan (2014), the initial step is to verify δ_1 in equation (8) and ε_1 in formula (9). The presence of both coefficients indicates that the mediating effect is statistically relevant. The next phase involves the validation of ε_2 in equation (9), If the finding is statistically meaningful, it suggests the presence of intermediate mediation pattern; conversely, if it shows no statistical relevance, this implies a full mediating effect. Last phase involves a comparative analysis. δ_1 and $\varepsilon_1 \varepsilon_2$ sign, If the identical symbol, it represents a limited mediating effect, regarding the extent of the mediating effect being quantified as follows $\delta_1 \varepsilon_1 / \alpha_1$. In the third phase,

a comparison is made the signs of δ_1 and $\varepsilon_1\varepsilon_2$. If the sign differs, it indicates a masking effect, and the extent of the intermediary effect is represented by the proportion $|\delta_1\varepsilon_1/\alpha_1|$.

Through this analysis, we can gain a deeper understanding of how green finance policies promote economic growth by fostering innovation and how this influence may vary under different regional conditions. This is of significant importance for formulating more effective regional innovation and financial policies.

3.3.4 Moderated Mediation Model

To gain a deeper insight into what are moderating variables affect the process of mediation (H3), this research refers to work conducted by Wen and Ye (2014) to introduce a moderated mediation model. By introducing the moderating variable, environmental pollution control intensity (EP), the model assesses its impact on the association between sustainable finance and its implications for regional economic development. This variable subsequently influences the indirect effect of sustainable finance on regional economic growth via regional innovation capacity (RIC). The detailed formulation of the model is presented below:

The GF and EP on the mediating variable of RIC:

$$RIC_{it} = a_0 + a_1 GF_i + a_2 \mathrm{EP} + a_3 (GF_{it} \times EP_{it}) + a_4 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.5$$

Impact of RIC (mediating factor) and EP (moderating factor) on regional economic growth (EH):

$$EH_{it} = b_0 + b_1 GF_i + b_2 RIC_{it} + b_3 EP_{it} + b_4 (GF_{it} \times EP_{it}) + b_5 Controls_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.6$$

According to the assessment conducted by Wen and Ye (2014), we first analyze a_3 in equation (10). If it is deemed significant, it indicates that the moderator variable (EP) affects the relationship between the independent variable (GF) and the mediator variable. (RIC_{it}). Next, we proceed to verify b_4 of the interaction indicator in the formula (11). Within this framework, significance means that the moderating indicator (EP) also influences the relationship between RIC_{it} and EH, thus validating the presence of a regulatory mediation effect.

Via this examination, it is possible to more comprehensively grasp the complex procedure of green finance policies on territorial prosperity pathways under different ecological stewardship systems intensities, providing a scientific basis for formulating differentiated environmental and financial policies.

3.3.5 Robustness and Heterogeneity Analyses

To guarantee the dependability of the empirical results, this research employs multiple robustness checks to address potential sources of bias and verify the consistency of the results.

(1) Dynamic Panel Model

To mitigate endogeneity concerns, particularly those arising from potential reverse causality, we estimate a dynamic panel model by including a one-period lag of green finance GF_{it-1}. This approach helps alleviate omitted variable bias and ensures that the observed correlation between GF and EH is not driven by simultaneity. Details of the model are summarized below:

$$EH_{it} = c_0 + c_1 GF_{it-1} + c_2 control_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.7$$

(2) Alternative Dependent Variable

To evaluate how the results are affected by the selection of the dependent variable, we replace the original high-quality economic development index (EH) with the natural logarithm of regional GDP (lngdp_{it}) and re-estimate the model:

$$\mathrm{lngdp}_{it} = d_0 + d_1 GF_{it} + d_2 control_{it} + \lambda_i + \mu_t + \epsilon_{it} \quad 3.8$$

This alternative indicator captures regional economic scale more directly. The consistency of estimation results across both specifications reinforces the robustness of the main conclusions.

(3) Bootstrap Estimation

To address potential issues related to heteroskedasticity and non-normality of the error term, we implement a bias-corrected block bootstrap procedure with 1,000 replications, preserving the panel data structure. The steps are as follows:

(a) Draw bootstrap samples by resampling cross-sectional units with replacement;

(b) Re-estimate the baseline model parameters $\alpha 1*$(b) for each bootstrap replication;

(c) Calculate the bootstrap standard errors and percentile-based 95% confidence intervals:

$$\mathrm{SE}_{\mathrm{boot}}(\alpha_1) = \sqrt{\frac{1}{B-1}\sum_{b=1}^{B}\left(\alpha_1^{*(b)} - \bar{\alpha}_1^{*}\right)^2}, \quad \bar{\alpha}_1^{*} = \frac{1}{B}\sum_{b=1}^{B}\alpha_1^{*(b)}$$

3.9

We derive the empirical distribution of $\alpha 1*(b)$ and construct the confidence interval. The research points to the fact that the confidence range for the core coefficient $\alpha 1$ zero falls outside the interval, confirming the statistical stability of the baseline outcomes.

(4) Temporal Robustness Check

In pursuit of assessing the consistency to the outcomes over time, we limit the sample period to the years 2017 to 2020, a more recent and intensive phase of China's green transition. This shortened period allows for assessing whether the observed effects persist Within the scope of accelerated eco-friendly growth. The consistency of the estimation results across different time frames further supports the dependability of our outcomes.

(5) Heterogeneity Investigation

To examine the variations in the effects of sustainable finance policies, we divide the entire observation pool into three subgroups: Eastern, Central, and Western regions. This classification is motivated by the following considerations:

(a) Systematic differences in industrial structure, resource endowments, and policy enforcement intensity across regions;

(b) Subsample comparisons allow for the identification of differentiated policy impacts;

(c) Empirical insights gained can inform the design of region-specific policy interventions.

CHAPTER 4
FINDINGS

4.1 Data description

Prior to conducting in-depth empirical analysis, this study first preprocesses the data to guarantee the dependability and strength of the assessment outcomes. Specifically, to minimize the potential bias caused by heteroscedasticity and outliers on the analysis outcomes, this study utilizes log-scale transformation to all factors and eliminates outliers from the two ends of the continuous data range (top 1%). This stage of data preprocessing contributes to enhancing the accuracy and efficiency of model estimation. Analyzing 420 recorded cases, a comprehensive data summarization analysis was conducted to display the fundamental properties of the data, which provide a strong basis for future empirical studies.

High-quality economic development (eh), the summary statistics reveal an average value of 0.293 along with a measure of variability of 0.129 This relatively large standard deviation indicates significant regional variations in the quality of economic development, reflecting the imbalance in regional economic development. The median value is 0.255, which is slightly below the mean, further suggesting that many regions have relatively lower levels of high-quality economic development. This finding implies that targeted policies may be necessary to enhance the development quality in these regions. The index ranges from 0.147 to 0.764, showing a substantial gap between the most and least developed regions. This disparity highlights the notable variations in economic development across different regions.

The Green Finance Development Index (gf) has an average of 0.152, accompanied by a standard deviation of 0.062. This standard deviation indicates significant regional differences in the advancement of sustainable finance; this reflects the imbalance in green finance development across regions. The index varies from 0.077 to 0.400, utilizing the 50th percentile (0.136) being marginally beneath the mean.

This suggests that advancement of sustainable finance is still at an intermediate level in most areas and has not yet reached a high level.

Regarding the control variables, the industrial structure (ind) exhibits a mean value of 0.418, accompanied by a standard deviation of 0.082, showing moderate variation across regions. Per capita GDP (lngdppc) has an average value of 10.68 with a moderately small variability (0.540), indicating a certain degree of stability in per capita GDP across regions. Other control variables, such as human capital expenditure (hep), government intervention (gov), openness (open), and R&D investment (rd), also show varying degrees of regional disparities. In particular, human capital expenditure (hep) and R&D investment (rd) show larger differences across regions, which may reflect the imbalance in education and technology investment among regions. The differences in government intervention (gov) and openness (open) may be related to the policy environment and the degree of economic openness in each region (See Table 4 for details).

These descriptive empirical results offer significant contributions to the empirical investigation, uncovering the spread pattern traits of each factor and their possible influence on the research results. Through these descriptive probabilistic analyses, we can better understand the structure and aspects of the data, providing a reliable underpinning for further in-depth analysis. These analysis results not only help identify potential issues in the data but also provide important references for model selection and variable processing.

Table 4 Descriptive statistics pertaining to the variables

variable	N	mean	p50	sd	min	max
eh	420	0.293	0.255	0.129	0.147	0.764
gf	420	0.152	0.136	0.062	0.077	0.400
ind	420	0.418	0.427	0.082	0.173	0.572

Table 4 (Continue)

variable	N	mean	p50	sd	min	max
lngdppc	420	10.68	10.68	0.540	9.185	12.14
hep	420	0.005	0.005	0.002	0.002	0.010
gov	420	0.031	0.029	0.0100	0.0130	0.061
open	420	91.56	96.85	59.51	8.001	224.3
rd	420	0.010	0.009	0.006	0.002	0.028

Source: The data calculation

4.2 Empirical Results

4.2.1 Multicollinearity Test

Assessment of multicollinearity is crucial prior to conducting regression analysis as it may impact the stability of model estimates and the precision of interpretation. This research utilizes the Variance Inflation Factor (VIF) as a methodological analytic and Tolerance metrics to evaluate multicollinearity, ensuring that the intercorrelations among the predictors set within the specified regression are not excessively high.

As depicted in Table 5, every variable has VIF values that are below the threshold of 4. The highest VIF value is observed for the "lngdppc" variable at 3.09, with an average VIF value of 1.93 across all variables, which is significantly lower than the generally recognized limit of 10. This suggests that there is an absence of significant multicollinearity among the explanatory variables within the model and their intercorrelations are within acceptable limits. The Tolerance values are all above 0.1, with the lowest being 0.324 for the "lngdppc" factor. Tolerance, being the reciprocal of VIF, is generally considered indicative of a non-problematic multicollinearity issue when its value exceeds 0.1.

These findings suggest there is an absence of substantial multicollinearity among the independent variables within the model, thus allowing for more confident

proceeding with subsequent regression analysis. This discovery is of notable relevance for ensuring the reliability of the model's estimated results and the validity of interpretations. By controlling for multicollinearity, the predictive power along with interpretative capacity of the model can be enhanced, thereby providing assurance for the accurate interpretation of research findings.

Table 5 Multiple covariance test

Variable	VIF	Tolerance
lngdppc	3.09	0.324
rd	2.76	0.363
ind	1.99	0.503
hep	1.65	0.606
open	1.45	0.690
gf	1.38	0.725
gov	1.18	0.845
Mean VIF	1.93	/

Source: The data calculation

4.2.2 Benchmark Regression Analysis

To extensively evaluate the contribution of GF on EH, this research constructs six distinct model specifications. The analytical outputs of the baseline causal inference estimation, which serve as the foundational assessment, are detailed in Table 6. These models are designed to progressively incorporate control variables and fixed effects to systematically integrate the robustness and reliability of the findings.

Model 1 includes solely the green finance variable, without incorporating control variables or fixed effects. The results indicate a coefficient of 0.746 for green finance, demonstrating. This suggests that, assuming no other influences are at play, green finance greatly contributes to the growth of regional economies. However, the R^2

value of 0.127 indicates limited explanatory power, with much of the variation remaining unexplained.

Model 2 builds on Model 1 by introducing multiple confounding adjustors, but without fixed effects. This improvement aims to adjust for other factors that may influence regional economic development, thereby providing a more accurate assessment of the role of green finance. The results show that the factor for green finance falls to 0.273. Notable control variables include industrial structure (ind) with a coefficient of -0.567, human capital expenditure (hep) at 11.079, and R&D investment (rd) at 10.498, all of which are important at the 1% significance level. The addition of these CV significantly enhances the model's explanatory power, with the R^2 value increasing to 0.636. This indicates that industrial structure, human capital expenditure, and R&D investment play important roles in regional economic development.

Model 3 further enhances Model 2 by incorporating chronological controls. The temporal adjustment through annual indicators aims to control for time trends and macroeconomic conditions that may affect regional economic advancement. The outcomes show that the coefficient for sustainable finance further drops to 0.180. Human capital expenditure (hep) gives a stronger positive effect, exhibiting a parameter estimate of 13.104, while R&D investment (rd) shows a reduced but still significant positive effect, with a coefficient of 4.334. The R^2 value increases to 0.859, indicating that the inclusion of year fixed effects further enhances the model's explanatory power.

Model 4 replaces year fixed effects with province fixed effects while retaining the control variables. The introduction of province fixed effects aims to account for heterogeneity across provinces, such as policy differences, geographical environments, and cultural backgrounds. The results show that the coefficient for GF becomes 0.132 (1% level). Human capital expenditure (hep) shows the strongest positive effect among all specifications, with a coefficient of 14.999. The R^2 value reaches 0.941, indicating that the provincial intercept adjustments further enhance the model's explanatory power and

highlights the significant impact of provincial heterogeneity on regional economic development.

Model 5 incorporates both province and year fixed effects along with control variables. This model aims to provide a comprehensive estimate by accounting for both temporal and spatial heterogeneity. The empirical evidence demonstrates that the factor for sustainable finance persists as statistically significant at 0.114. Human capital expenditure (hep) continues to exhibit a strong positive effect, with a coefficient of 15.825. This model achieves the highest R^2 value of 0.964, indicating that the joint use of province and year fixed effects further enhances the model's explanatory power and underscores the significant impact of both temporal and spatial heterogeneity on regional economic development.

Model 6 employs a stochastic influences approach. This model allows for personal impacts to be correlated with the explanatory variables, thereby providing a more flexible estimation framework. The results show that the factor for GF is 0.091, significant at the 10% level. Human capital expenditure (hep) continues to show a statistically and economically significant impact, exhibiting a statistically significant estimate of 15.500, whereas R&D investment (rd) shows a moderate favorable outcome, with a coefficient of 2.192. The R^2 value is 0.517, indicating that the random effects model has some limitations in explaining regional economic development but still offers a valuable complementary perspective.

Overall, the association between GF and EH remains consistently positive across different models, although the magnitude of the impact varies Human capital expenditure is highly significant across all model specifications, highlighting its crucial role in regional economic advancement. The progressive refinement and extensive analysis of these models not only enhance the robustness of the results but also provide a more thorough comprehension of the function of GF in the context of EH.

Table 6 Benchmark regression results

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	eh	eh	eh	eh	eh	eh
gf	0.746***	0.273***	0.180***	0.132***	0.114***	0.091*
	(0.095)	(0.073)	(0.049)	(0.042)	(0.033)	(0.054)
ind	/	-0.567***	-0.752***	-0.075	-0.152***	-0.116*
		(0.066)	(0.038)	(0.085)	(0.029)	(0.059)
lngdppc	/	0.037***	0.180***	0.028***	-0.043***	0.023**
		(0.013)	(0.003)	(0.009)	(0.013)	(0.010)
hep	/	11.079***	13.104***	14.999***	15.825***	15.500***
		(3.236)	(1.442)	(4.712)	(3.838)	(4.124)
gov	/	-0.572	-0.347	0.478	0.008	0.371
		(0.402)	(0.322)	(0.338)	(0.203)	(0.278)
open	/	0.055***	0.060*	0.057	0.065	0.064***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
rd	/	10.498***	4.334***	-0.441	0.494	2.192**
		(1.106)	(0.557)	(1.457)	(0.891)	(1.005)
Constant	0.180***	-0.027	-1.445***	-0.003	0.754***	0.030
	(0.016)	(0.137)	(0.032)	(0.088)	(0.135)	(0.109)
Observations	420	420	420	420	420	420
Prov FE	NO	NO	NO	YES	YES	NO
Year FE	NO	NO	YES	NO	YES	NO
R^2	0.127	0.636	0.859	0.941	0.964	0.517

Source: The data calculation

Note: The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. The table includes robust standard errors presented in parentheses.

4.2.3 Analysis of Mediating and Moderating Effects

The analysis focuses on the mediating role of regional innovation capacity (ric) and the moderating effect of environmental pollution control intensity (EP). Additionally, regional binary indicators are included in the models to regulate for regional heterogeneity. The detailed empirical findings are tabulated in Table 7.

Table 7 Moderated and Mediated Effects Test

VARIABLES	Model 7	Model 8		Model 9	
	eh	lnric	eh	lnric	eh
lnric	/	/	0.111***	/	0.101***
			(0.014)		(0.021)
gf	-0.009	0.730***	0.099**	0.544***	-0.064
	(0.065)	(0.076)	(0.045)	(0.179)	(0.055)
EP	-3.472***	/	/	3.431	3.098***
	(0.659)			(3.348)	(0.589)
gfep	15.043***	/	/	6.303*	14.533***
	(3.694)			(15.896)	(3.245)
ind	-0.756***	-1.269***	-0.653***	-1.187***	-0.637***
	(0.048)	(0.098)	(0.027)	(0.128)	(0.028)
lngdppc	0.180***	0.509***	0.131***	0.502***	0.129***
	(0.003)	(0.025)	(0.007)	(0.024)	(0.012)
hep	12.962***	5.868	14.116***	4.288	12.530***
	(1.383)	(3.340)	(1.683)	(3.109)	(1.504)
gov	-0.296	-1.600**	-0.134	-1.251*	-0.170
	(0.305)	(0.685)	(0.287)	(0.588)	(0.288)
open	0.000	0.002***	-0.000**	0.002***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 8 (Continue)

VARIABLES	Model 7	Model 8		Model 9	
	eh	lnric	eh	eh	lnric
rd	4.470***	18.176***	2.328***	17.062***	2.750***
	(0.570)	(1.297)	(0.288)	(1.406)	(0.289)
group	0.014***	0.186***	0.001***	0.168***	0.003***
	(0.003)	(0.014)	(0.005)	(0.015)	(0.005)
Constant	-1.403***	-2.062***	-1.303***	-1.187***	-1.206***
	(0.033)	(0.232)	(0.038)	(0.158)	(0.064)
Observations	420	420	420	420	420
Prov FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
R^2	0.866	0.832	0.871	0.847	0.874
Sobel Z	/	5.318		0.445	
Sobel Z-p value	/	0.001		0.046	
bootstrap Z	/	3.99		3.36	
bootstrap Z-p value	/	0.001		0.020	
Percentage of intermediary effects	/	55.4%		19.5%	

Source: The data calculation

Note: Same as in Table 6.

Fundamentally, Model 7 examines the moderating effect of environmental pollution control intensity (EP) on the association between GF and EH. This examination aims to uncover how stringent environmental policies influence the favorable influence of GF on EH. The findings indicate that the factor for the interaction term (gfep) is 15.043,

showing a notable moderating influence. This suggests that stringent environmental policies significantly enhance the positive effectiveness of green finance in driving regional economic growth. The R^2 value of this model is 0.866, demonstrating good explanatory power and indicating that the econometric specification effectively captures the relationships among the regressors.

Next, the research examines the mediating function of innovation at the regional level capacity (lnric). To examine this proposition, a mediating structure (Model 8) is constructed. This analysis aims to reveal how green finance promotes regional economic development through enhancing regional innovation capacity. The findings from Model 8 indicate that GF exerts a substantial positive influence on the ability for local innovation, with a coefficient of 0.730 (p<0.01). This indicates that sustainable finance effectively encourages regions to enhance their innovation capabilities, thereby providing new momentum for economic development. Additionally, regional innovation capacity significantly contributes to EH, exhibiting a factor of 0.111. The factor of green finance continues to be important at 0.099 (p<0.05), further verifying the detection of a non-full mediation role. The Z-score computed via the Sobel method is 5.318 (p<0.05), while Z-statistic computed using the Bootstrap technique is 3.99 (p<0.05). Notably, the mediation effect accounts for 55.4% of the total effect, highlighting the critical role of regional innovation capacity as a key intermediary. This result suggests that a significant portion of the influence of GF on EH is mediated through enhanced regional innovation capacity.

In addition to examining direct and mediating effects, the study further explores the moderating mediation effect of environmental pollution control intensity (EP). Specifically, this analysis investigates how EP influences the pathway through which green finance affects regional economic development. Model 9 shows that parameter associated with the interaction term (gfep) is 6.303 (p<0.1). This suggests that EP enhances the beneficial impact of GF on regional innovation capacity, thereby amplifying the

mediation effect. The direct impact of EP on regional economic development remains significant, with a factor of 3.098 (p<0.01). The Sobel Z-value for the moderating effect is 0.445 (p<0.05), and the Bootstrap Z-value is 0.020 (p<0.05), with the moderating mediation effect accounting for 19.5% of the total mediation effect. This result further demonstrates that stringent environmental policies not only directly enhance the effectiveness of green finance but also amplify its impact on regional economic development by strengthening regional innovation capacity.

Overall, the results emphasize the critical roles of regional innovation capacity and environmental pollution control intensity in mediating and moderating the influences of GF on EH. These findings reveal the priority of green finance in facilitating sustainable economic advancement through enhanced regional innovation capacity and stringent environmental policies. These insights are valuable for policymakers aiming to leverage green finance to drive sustainable regional economic growth (As shown in figure 8).

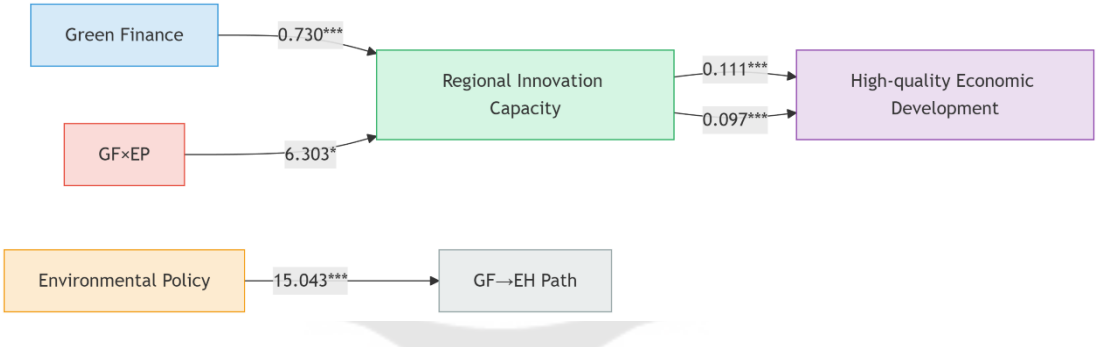

Figure 8 Mediating and Moderating Effects

The analysis also explores the moderating mediation effect based on quantiles, as illustrated in Figure 9. The plot displays the coefficients of the mediation variable, regional innovation capacity (RIC), across different quantiles of the moderating variable, environmental pollution control intensity (EP).

The findings suggest that the factor of the mediation variable (RIC) remains relatively stable across the lower to middle quantiles, averaging around 0.10. However, as the quantile level increases, particularly beyond the 50th percentile, there is a slight

upward trend, peaking at approximately 0.14 in the 75th percentile before stabilizing. The confidence interval remains narrow throughout, suggesting a consistent mediation effect across varying levels of EP.

In conclusion, the findings underscore the significant role of regional innovation capacity as a mediator in the relationship between green finance and regional economic development, particularly across different levels of environmental pollution control intensity. This insight is valuable for policymakers aiming to enhance regional innovation through targeted interventions in sustainable finance and environmental management.

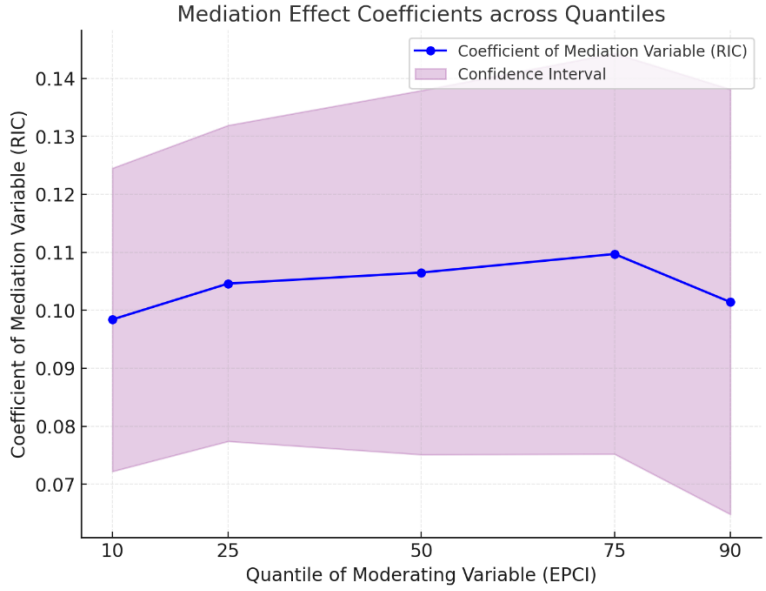

Figure 9 Quantile moderation effect plot

4.3 Robustness and Heterogeneity Analysis

4.3.1 Robustness Tests

For the purpose of guaranteeing the dependability of the research outcomes, this research carried out stability assessments on the relationship between GF and EH from multiple perspectives. Table 8 presents the results of four distinct methods, including addressing endogeneity issues, using alternative dependent variables, non-parametric validation, and testing temporal stability. These multi-dimensional tests show a high degree of consistency, significantly enhancing the credibility of the baseline

findings.

(1) Addressing Endogeneity via Lagged Independent Variables

Endogeneity issues can potentially distort the identification of causal relationships in empirical research. To effectively address potential reverse causality problems, this study employed a dynamic panel model incorporating a one-period lagged green finance variable (GF_{it-1}). This method helps to mitigate the simultaneous bias that could demonstrate stochastic dependence in the data-generating process. According to Column 1 of Table 8, the estimated factor for green finance is 0.194 ($p<0.01$), which is highly consistent with the baseline estimate. This persistence suggests that omitted variable bias is unlikely to drive the observed relationship, thus satisfying the exclusion restriction requirement for valid instrumentation. This buttresses the idea that GF serves as a pivotal determinant in accelerating EH, and this impact remains robust even after considering endogeneity issues.

(2) Measurement Robustness: Alternative Dependent Variable

To test the sensitivity of the measurements, the primary development metric (eh) was replaced with regional GDP (lnGDP). The adoption of this alternative indicator aims to assess the impact of different measurement approaches on the research results, thereby enhancing the robustness of the conclusions. Column 2 shows that when regional GDP functions as the dependent variable, the factor for GF rises to 0.787 ($p<0.05$). This result may reflect the broader capture of economic externalities by GDP, especially in determining the overall degree of territorial economic maturity. The sustained statistical significance across different outcome variables further underscores the generalizability of the results beyond specific development indices (Kmenta, 2010). This indicates that regardless of the measurement approach used, the beneficial effects of GF on EH remains highly robust.

(3) Non-Parametric Validation: Bootstrap Resampling

In statistical analysis, the distributional assumptions of the model can

significantly affect the veracity of the outcomes. To further validate the robustness of the model, this study employed the bias-corrected bootstrap procedure with 1,000 replications (Hesterberg, 2011). Bootstrap resampling is a non-parametric statistical method that can effectively assess the stability and reliability of model estimates, especially when the sample size is small or the distributional assumptions are unclear. Column 3 shows that after bootstrap resampling, the factor for GF is 0.180 ($p<0.01$). The narrow confidence intervals (available upon request) and minimal deviation from the baseline estimates confirm the structural stability of our model against distributional assumptions. This indicates that even under different distributional assumptions, the beneficial effect of GF on EH remains robust.

(4) Temporal Stability: Restricted Sample Period

To assess temporal heterogeneity, the analysis window was truncated to 2017-2020 (Column 4). This period coincides with a critical phase of China's green transition, and by restricting the sample period, the study can more accurately assess the impact of green finance during this specific stage. Despite the reduced sample size, the sign of the green finance coefficient stays positive (0.144, $p<0.01$), indicating that the beneficial effect of GF on EH is persistent during China's intensive green transition phase. Although limited time spans may reduce statistical power (Hsiang, 2016), the sustained significance across specifications mitigates such concerns. This further validates the stable promoting influence of green finance on regional economic advancement across different time periods.

Through a series of rigorous robustness tests, this study has verified the reliability of the influence of GF on EH from multiple perspectives. These tests cover the handling of endogeneity issues, the substitution of measurement indicators, non-parametric validation, and temporal restrictions (temporal validity). These comprehensive test results collectively satisfy the tripartite robustness criteria outlined by Leamer (1983). Collectively, the consistency of these examination outcomes

significantly reduces the risk of framework dependency along with provides a more solid basis for interpreting the causal connection between GF and EH. This multidimensional robustness validation approach further ensures the applicability and universality of the research conclusions in different contexts, offering reliable empirical support for subsequent policy formulation and theoretical expansion.

Table 9 Robustness tests

VARIABLES	(1)	(2)	(3)	(4)
	eh	lngdp	eh	eh
gf	/	0.787**	0.180***	0.144***
		(0.313)	(0.049)	(0.021)
gfl1	0.194***	/	/	/
	(0.043)			
ind	-0.758***	0.234	-0.752***	-0.956***
	(0.042)	(0.160)	(0.037)	(0.078)
lngdppc	0.182***	1.051***	0.180***	0.165***
	(0.004)	(0.061)	(0.003)	(0.006)
hep	13.836***	7.802	13.104***	17.589***
	(1.358)	(5.750)	(1.475)	(1.041)
gov	-0.404	-9.289***	-0.347	0.530***
	(0.351)	(1.669)	(0.313)	(0.069)
open	0.042**	0.030***	0.043**	0.034
	(0.021)	(0.022)	(0.023)	(0.024)
rd	4.201***	0.392	4.334***	7.189***
	(0.571)	(2.943)	(0.548)	(1.192)
Constant	-1.478***	-2.465***	-1.445***	-1.362***
	(0.043)	(0.566)	(0.041)	(0.053)
Observations	390	420	420	120

Table 8 (Continue)

VARIABLES	(1)	(2)	(3)	(4)
	eh	lngdp	eh	eh
Prov FE	YES	YES	420	NO
Year FE	YES	YES	0.859	YES
R^2	0.855	0.837	0.859	0.882

Source: The data calculation

Note: Same as in Table 6.

4.3.2 Heterogeneity Test

To explore the differentiated effects of GF in various regions, the sample was categorized into 3 distinct regions for separate regression investigation. This methodology facilitates for a more precise investigation of differences in economic development levels, financial infrastructure, and policy implementation effectiveness across regions. All models accounted for both annual and provincial fixed effects to control for potential influences of time trends and region-specific factors, with high R^2 values indicating a strong model fit (as shown in table 9).

In the eastern area, GF has a significantly beneficial effect on EH, with a regression coefficient of 0.196 ($p<0.01$). This finding indicates that the sophisticated financial systems in the eastern region can efficiently channel green finance into catalysts for regional economic growth. Additionally, variables such as per capita GDP (lngdppc), industrialization level (ind), and per capita health expenditure (hep) also demonstrate significant positive impacts on economic development in this region, further highlighting the eastern region's advantages in economic foundation and public services.

In the central region, the regression factor for GF is 0.265 ($p<0.01$), showing an even more robust positive effect in comparison the eastern area. It may be ascribed to

the central region's pivotal role in the implementation of green finance policies, suggesting that its policy enforcement and resource allocation efficiency might surpass those of other regions. Moreover, R&D investment (rd) has a significant positive coefficient of 2.760 ($p<0.01$), underscoring its essential function in promoting robust EH in this region, potentially representing a new growth driver for the central region.

In the western region, the regression coefficient for green finance is 0.128 ($p<0.01$), lower than those of the eastern and central regions. This may reflect the weaker financial infrastructure in the western region, which limits the efficacy of green finance in driving economic development. However, R&D investment (rd) exhibits a significant positive coefficient of 8.345 ($p<0.01$), indicating that EH in the western region heavily relies on the backing of research and development efforts. This suggests that enhancing R&D investment to boost innovation capacity might be a key pathway to achieving sustainable economic development in the western region.

In summary, the heterogeneity analysis reveals significant regional disparities in the influence of green finance on regional economic development. These disparities are likely to be associated with differences in regional economic development levels, the maturity of the financial system, and the effectiveness of policy implementation. Therefore, policymakers should consider these regional differences when formulating green finance policies and adopt targeted measures to enhance the overall effectiveness of green finance in promoting regional economic development. The detailed data in Table 9 further support these conclusions and provide empirical evidence for the formulation of region-specific policies.

Table 10 Heterogeneity tests

VARIABLES	East eh	Central eh	West eh
gf	0.196***	0.265***	0.128***
	(0.043)	(0.062)	(0.025)
ind	0.811***	0.030	0.708***
	(0.054)	(0.031)	(0.079)
lngdppc	0.213***	0.024	0.022**
	(0.015)	(0.023)	(0.010)
hep	20.407***	9.641**	14.829***
	(4.865)	(3.535)	(3.338)
gov	-0.370	-0.271	1.287***
	(0.262)	(0.364)	(0.216)
open	0.050***	0.045**	0.055***
	(0.000)	(0.000)	(0.000)
rd	1.988	2.760***	8.345***
	(1.208)	(0.881)	(1.152)
Constant	-1.807***	-0.136	0.134
	(0.164)	(0.235)	(0.102)
Observations	168	126	126
Prov FE	YES	YES	YES
Year FE	YES	YES	YES
R^2	0.904	0.695	0.833

Source: The data calculation

Note: Same as in Table 6.

CHAPTER 5
CONCLUSION, POLICY IMPLICATIONS AND DISCUSSION

5.1 Main Conclusions

Amid intensifying planetary warming trends and the pursuit of top-notch economic growth, China faces the dual challenges of intensified resource and environmental constraints and insufficient endogenous drivers of economic progress. This analysis conducted here methodically examines the way green finance influences economic growth in different regions. particularly its driving role in technical advancement, by formulating a Green Finance Development Index (GFDI) and employing fixed-effects models, mediation analysis, and moderation-based mediation structures. The research utilizes panel data from 30 provinces in China spanning from 2008 to 2021, with the goal of uncovering how green finance contributes to the advancement of high-quality regional economic development and the mechanisms that support this process.

This research indicates that green finance plays a crucial role in promoting high-quality economic growth in regions, with regional innovation capacity playing a pivotal transmission channel in this process. Specifically, green finance effectively enhances regional innovation capacity by supporting green technological innovation and optimizing resource allocation, thereby promoting economic growth. Additionally, the intensification of environmental pollution control further amplifies the positive impact of green finance, indicating that stringent environmental policies can effectively enhance the importance of green finance in fostering economic development in specific regions.

Nonetheless, the effectiveness of green finance varies significantly across different regions. Economically developed areas, with their sophisticated financial infrastructure and mature innovation ecosystems, are able to utilize green finance resources more effectively, thereby gaining greater economic growth benefits. In contrast, less developed areas, constrained by a lack of financial resources and weak innovation foundations, experience more limited effects from green finance. This

regional heterogeneity suggests that formulating differentiated green finance policies is crucial for achieving balanced regional development.

In summary, green finance significantly promotes high-quality regional economic development by enhancing regional innovation capacity. Simultaneously, the intensification of environmental pollution control further reinforces the positive effectiveness of green finance. Nonetheless, the varying effects of green finance across regions necessitate that policymakers fully consider geographical differences when crafting green finance regulations to achieve balanced regional development. This research not only deepens the theoretical knowledge of green finance in relation to high-quality regional economic development but also offers policymakers a scientific foundation for making decisions that improve the efficacy of green finance on fostering sustainable advancement. The findings emphasize the critical role of regional technological advancement capacity and environmental governance in fully realizing the prospects of green finance in facilitating the attainment of sustainable development objectives.

5.2 Policy Implications

Initially, improve the green finance policy structure to increase the effectiveness of resource distribution in green finance. From one perspective, the scale of China's green finance market is relatively small, making it difficult to meet the massive green investment demands required for the objectives underlying "carbon peaking by 2030" and "carbon neutrality by 2060." For example, in 2023, China's green credit balance reached 27.2 trillion-yuan, accounting for only about 10% of the total loan balance of financial institutions, and the market size of green bonds and carbon emission trading is even more limited. On the other hand, the imbalance in the structure of green finance is prominent, with green credit accounting for too high a proportion of green finance products, while the advancement of direct financing financial instruments including climate-aligned securities and carbon finance lags behind. Accordingly, it is

fundamental to enhance the green finance policy framework, increase the size of the green finance market, and refine the composition of green finance instruments in the future. Specific actions to achieve this include:

(1)Increasing the size of the green finance market

The government ought to enhance its support for sustainable financial initiatives, guiding expanded social capital into the sphere of sustainable capital allocation through policy tools including fiscal subsidies and tax incentives. Simultaneously, promote the development of innovative green finance products and services by financial institutions, expanding the variety of offerings to include options like climate-aligned investment vehicles, environmental risk mitigation products, and emissions trading mechanisms to accommodate the requirements of various organizations and projects.

(2)Optimizing the structure of green finance products

It is advisable to diminish the overdependence on green credit and to foster the creation of direct financing instruments, including green bonds and carbon finance. The government may consider the establishment of dedicated funds aimed at advancing green finance, which would facilitate support for green technological innovation and the growth of green industries. Concurrently, it is essential to promote a comprehensive integration of the green finance market with the capital market, thereby enhancing the liquidity and efficiency of the green finance sector.

(3)Improving the green finance standard system

Develop unified green finance standards and certification systems, clarify the definition standards and evaluation methods for green projects, and improve the transparency and credibility of the green finance market. Enhance the development of the green finance information disclosure system, requiring financial institutions and enterprises to regularly disclose the use of green finance funds and environmental benefits to prevent "greenwashing" behavior.

Second, strengthen regional innovation capacity building to enhance the level

of eco-friendly technological advancements. However, there are significant differences in innovation infrastructure and innovation capacity across various geographical areas, resulting in varying degrees of promotion of regional economic growth by green finance. Therefore, in the future, it will be essential to enhance regional innovation capacity building and elevate the advancement of environmentally sustainable technological innovation. Specific measures include:

(1)Increasing R&D investment

The government ought to boost funding for research in green technology, develop exclusive research funds, fostering participation from universities and research organizations to conduct research on green technological innovations. Simultaneously, guide organizations are encouraged to enhance their investment in research and development (R&D) and to foster independent innovation capabilities, and encourage the use of environmentally friendly technology in industry.

(2)Enhancing the development of innovation platforms

Build a number of high-level green technology innovation platforms, such as green technology R&D centers and green technology incubators, to provide one-stop services for enterprises and research institutions in technology R&D, achievement transformation, and talent training.

(3)Optimizing innovation policy environment

Improve the system for safeguarding intellectual property, enhance the safeguarding of green technology innovation achievements, and stimulate the enthusiasm of enterprises and researchers for innovation. Develop preferential policies aimed at attracting top-tier talent and innovative teams to the region engage in the field of green technological innovation, providing talent support for regional innovation capacity building.

Thirdly, it is essential to develop sustainable finance policies that are tailored to the specific local conditions in order to facilitate harmonious regional development.

Developed regions can utilize more efficiently green finance resources due to their sophisticated financial infrastructure and mature innovation ecosystems, while underdeveloped regions face the dual difficulties of an absence of financial resources along with a weak innovation foundation. Consequently, it is imperative to develop green finance policies that are tailored to the specific circumstances of each locality in the future to promote coordinated regional development. Specific measures include:

(1)Implementing differentiated green finance policies

Formulate differentiated green finance policies based on the level of economic development and the structure of industry, and environmental conditions spanning diverse territorial jurisdictions. For developed regions, encourage them to take the lead in green finance innovation and green industry development, playing a demonstration and leading role; for underdeveloped regions, focus on strengthening the construction of financial infrastructure and innovation capacity, and improving the level of green finance development.

(2)Strengthening regional green finance cooperation

Establish regional green finance cooperation mechanisms to promote the rational flow and optimal allocation of green finance resources among regions. Encourage financial institutions in developed regions to cooperate with those in underdeveloped regions to jointly support green projects and the advancement of green industries. Encourage the integration of regional green finance markets to enhance the overall effectiveness of the green finance sector.

(3)Improving the green finance regulatory system

Strengthen sustainable finance supervision to prevent sustainable finance risks. Develop along with enhance mechanisms for assessing risks associated with green finance and for providing early warnings, Optimize the environmental benefit assessment and risk monitoring of sustainable finance projects, and ensure the safety and effective use of sustainable finance funds. At the same time, strengthen the

supervision of the green finance market, regulate market order, and maintain market stability.

In summary, green finance plays an important role in promoting high-quality regional economic development, but its development still faces many challenges. In the future, it is necessary to enhance the efficiency of green finance resource allocation, promote coordinated regional development, and provide strong support through measures such as optimizing the green finance policy framework, strengthening regional innovation capacity building, and formulating green finance policies according to local conditions.

5.3 Discussion

The results of this study offer a valuable addition to the current body of work on green finance and economic progress within regions. By systematically analyzing the impact mechanism of green finance on regional economic growth and its regional differences, the present analysis uncovers the key contribution of technological innovation as an intermediary in the connection between green finance and economic advancement. This discovery is in alignment with the extensive research on innovation-driven development, emphasizing the core position of technological innovation in promoting high-quality regional economic development. Additionally, this paper highlights the importance of environmental pollution control intensity as a moderating factor, indicating that stringent environmental policies can significantly enhance the effectiveness of green finance. This conclusion resonates with research emphasizing the beneficial effect of environmental governance on balanced progress.

The manifestation of regional heterogeneity in the impact of green finance is particularly noteworthy. The more economically developed eastern and central regions benefit more from green finance due to their sophisticated financial infrastructure and mature innovation ecosystems. This finding echoes the literature on regional economic development disparities, which typically attribute these disparities to differences in

institutional quality, financial development, and technological capabilities. The comparatively limited effect of sustainable capital flows across western provinces highlights the need to create specific policies aimed at correcting regional disparities and promoting inclusive growth.

Future research should further explore how green finance drives innovation and growth at the micro level. A promising research direction is to explore the mediating role of R&D investment along with the moderating influences of regional innovation capability and green credit availability. This research direction can deepen the comprehension of how green finance translates into innovation performance and regional competitiveness. Specifically, future studies can investigate the intermediary role of R&D investment in the relationship between green finance and the performance of corporate innovation. analyzing how green finance enhances corporate green technological innovation capabilities by increasing R&D investment through firm-level data. At the same time, research on how regional innovation capacity moderates the effects of environmentally sustainable finance on corporate innovation and economic growth is needed, as the innovation ecosystems in different regions may respond differently to green finance, which requires empirical verification. Additionally, analyzing how the availability of green credit affects corporate green innovation behavior, exploring the influence of the difficulty and cost of obtaining green credit on green innovation through firm-level credit data, is also an important direction for future research.

Moreover, future research can incorporate industry-level data or firm-level panel data to examine the heterogeneity effects across different industries. For example, high-polluting industries and low-carbon industries may exhibit different innovation and growth performances under the support of green finance. Investigating the conditional influences of industry-specific policies on the effectiveness of green finance, exemplified by government fiscal incentives and levies incentives for specific industries, which may affect the implementation of green finance, is also an important direction for future

research.

Lastly, using time-series data to analyze the sustained dynamics over an extended period effects and exploring the impact at different time scales through panel data models, constitutes a critical knowledge gap warranting investigation. Studying the dynamic mechanisms of green finance on economic advancement, including the long-term impacts on technological progress, industrial structure adjustment, and environmental quality improvement, can provide policymakers with more scientific decision-making bases to promote the significance of green finance in promoting sustainable development.

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