

## Article

# Green Credit Subsidies and Green Total Factor Productivity—Evidence from the Chinese Market

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## Abstract

Sustainable finance serves as a critical institutional lever for steering the national economic system toward a green transition, while the sustained rise in ecologically integrated output efficiency provides an important breakthrough for resolving the long-standing apparent tension between growth performance and ecological quality. Drawing on panel data from 30 provincial-level administrative units in China over the period 2005–2022, and employing a non-radial efficiency measurement index, a difference-in-differences identification strategy, and a synthetic comparative analysis method, this paper systematically examines the policy intervention effects and transmission mechanisms of the ecological loan interest compensation system on regional ecologically integrated output efficiency. The empirical results indicate that, within the sample observation window, following the implementation of the ecological loan interest compensation system, the ecologically integrated output efficiency of all provinces generally exhibited an upward trend, and the system exerted a significant positive driving effect on efficiency improvement. Transmission mechanism tests reveal that increased R&D and innovation activity, expanded sustainable credit scale, and optimization of industrial hierarchical structures constitute important intermediate links in the chain of policy effect transmission. Conditional effect analysis further reveals that the intervention effects of this system display a pronounced uneven distribution pattern across geographical space.

**Keywords:** green credit subsidies; GTFP; green credit policy; sustainable finance

## 1. Introduction

Retrospectively examining China's economic path since 1978, its real GDP expanded from RMB 360 billion in 1979 to RMB 136 trillion in 2025, representing a gain of approximately 350 times. This remarkable growth trajectory is unequivocally evidenced by the longitudinal data compiled by the nation's official statistical agencies. This traditional development model, dominated by resource-intensive industries, has supported high-speed economic growth in specific historical stages, but has led to energy consumption intensity exceeding the environmental carrying capacity threshold, forming a binary opposition pattern between ecological development and economic progress. Formulating a strategic layout for ecological and environmental protection and accelerating the construction of a development system that is environmentally friendly, sustainable, and low-energy-consuming has become the essential pathway to transcend the "growth bottleneck". It requires systematic projects, such as an industrial structure cleaning transformation and a

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low-carbon energy consumption transformation, to achieve the coordinated improvement of development quality and ecological benefits. This strategic shift not only aligns with the “carbon neutrality” goal of global climate governance but also represents a key practical route to sustainable economic growth in the emerging societal framework.

GTFP, as a new sustainable paradigm, is characterized by the organic synergy between economic growth and resource and environmental benefits. The core essence of this indicator’s upward trajectory is to drive the restructuring of social production processes alongside the continuous upgrading of clean technologies, to promote the evolution of economic development models towards an intensive ecological paradigm through the endogenous mechanism of environmental costs throughout the entire lifecycle. The establishment of a market-oriented trading mechanism for resource and environmental factors marks a systemic breakthrough in China’s ecological governance system: relying on the three institutional pillars of property rights definition, price formation, and transaction circulation, it drives the systematic optimization of factor allocation efficiency. This institutional innovation promotes a market-oriented correction of negative externalities in the environment. At the same time, it has formed an endogenous growth mechanism of GTFP by improving production efficiency and scale efficiency, thereby promoting a dynamic balance between economic development and ecological and environmental capacity. The environmental policy tools that effectively promote the improvement of GTFP include environmental taxes and emissions trading, which incentivize emission reduction and innovation through price signals; command-based regulation drives industrial upgrading; and green credit subsidies reduce the financing costs of green projects. This article mainly studies the impact of green credit subsidies on GTFP.

Green finance, fundamentally, is a collaborative governance mechanism between the public sector and market entities, with institutional implications that go beyond traditional financial services and encompass policy toolbox design, cross-departmental regulatory frameworks, and resource allocation rules guided by national strategies. The efficient green finance system relies on risk compensation mechanisms and cross-period resource allocation functions and drives the leap of GTFP through the Pareto improvement of capital factors. Existing research has mostly focused on single-dimensional policy tool analysis paradigms, such as independent policy modules, such as central bank green credit guidelines or special fiscal subsidies. However, empirical evidence reveals significant limitations of a single policy: financial institutions face incentive gaps caused by information asymmetry under the green credit framework, manifested as insufficient compensation for long-term project risk premiums, lack of maturity conversion mechanisms, and imbalanced return risk ratios; the fiscal subsidy policy leads to adverse selection due to the principal–agent relationship, inducing distortion of strategic information disclosure and subsidy dependence in enterprises. There are three structural differences among policy entities: bureaucratic losses in information transmission channels, diminishing marginal effects of incentive structures, and departmental boundary constraints on execution efficiency. To solve this dilemma, it is necessary to construct a Nash equilibrium solution with multi-policy coordination, among which the green loan interest subsidy policy has typical institutional innovation value: through the composite tool of fiscal targeted interest subsidy and financial market-oriented pricing, a dual mechanism of risk sharing and signal transmission is formed, achieving cross-departmental resource integration and policy multiplier effect. This study primarily focuses on the practice of local government green interest subsidy policies. From the perspective of policy coordination between monetary authorities and fiscal authorities, it reveals the micro-level transmission pathways through which green productivity is enhanced. Furthermore, it provides a new theoretical modeling paradigm and a policy evaluation benchmark system for improving the green finance framework.

The green credit interest subsidy system is an important institutional innovation for the Chinese government to build a green finance system. Through the coordination mechanism of top-level institutional design and local fiscal incentives, it effectively promotes the marketization process of green project financing. This policy framework adopts the fiscal and financial policy coordination tool to implement targeted interest rate subsidies for financing of enterprises that meet the national green industry standards. Specifically, the policy covers the interest difference in loans issued by commercial institutes and other financial banks through the special fiscal subsidy mechanism and is managed by the local fiscal budget special account for fund coordination. The selection criteria for green credit subsidy projects usually include: the project complies with the national green industry catalog, has quantifiable environmental benefits (such as carbon emissions reduction)/mature and reliable technology or equipment, good corporate credit and compliance records, clear and dedicated loan fund uses, priority support for certified green projects, or applications included in local pilot lists. As of July 2024, statistical data show that 22 provincial-level administrative regions in China have completed policy support deployment, forming a multi-level policy implementation system. Compared to traditional single policy tools, the green credit interest subsidy system has dual institutional advantages. Firstly, compared with the market-oriented green credit mechanism, this policy lowers the financing cost of green projects below the market equilibrium interest rate through fiscal subsidies, thereby effectively resolving the risk premium dilemma faced by financial institutions in green projects. This risk compensation mechanism significantly enhances the willingness of commercial banks to provide green credit, thereby forming a virtuous cycle in the green finance market. Under this mechanism, green manufacturing enterprises are able to break through the bottleneck of financing constraints and invest low-cost funds in key areas such as green technology research and development, intelligent equipment upgrading, and clean production process transformation, thereby achieving a dual improvement in environmental and economic benefits. Secondly, compared to the independent fiscal subsidy policy, this system innovatively constructs a “fiscal financial” collaborative regulatory framework. By embedding the bank credit review mechanism into the policy implementation process, a dual verification system for corporate green qualifications is formed. This institutional design can not only utilize the information screening advantages of financial institutions in credit risk assessment but also guide market resource allocation through the leverage effect of fiscal funds. Under this institutional framework, enterprises must disclose complete green production information to commercial banks to obtain credit qualifications, and then complete subsidy applications through the financial system, effectively avoiding the information asymmetry and moral hazard problems commonly found in traditional subsidy policies. This two-pronged regulatory framework has significantly driven the orderly upgrading of eco-friendly producers and hastened the manufacturing sector’s transition toward a carbon-neutral, closed-loop operating model.

The core logic of ecologically oriented credit support policies lies in remedying the institutional deficiency within traditional capital allocation systems, namely, the insufficient incentives for environmental investment. The implementation pathway involves leveraging instruments such as fiscal interest subsidies, risk mitigation mechanisms, or differentiated pricing to guide commercial banks in reallocating credit flows from high-carbon and high-emission sectors toward emerging arenas, including clean energy and low-carbon transportation. This, in turn, alleviates the difficulties enterprises face in accessing funds and the high costs of capital utilization—challenges arising from protracted technology R&D cycles and a paucity of pledgeable collateral. Such institutional arrangements are anticipated to generate three tiers of effects: at the environmental level, accelerating pollution abatement and greenhouse gas emission control processes, thereby driving steady improvements in ecosystem quality; at the economic level, steering industrial

structures toward cleaner iterations, cultivating new drivers of growth, and fostering a virtuous feedback loop between green technologies and green capital; and at the social level, expanding ecological employment opportunities, reinforcing public awareness and endorsement of sustainable development, and safeguarding the stability of the financial system by reducing environmental risk exposure. In sum, the mechanism is committed to achieving a synergistic enhancement of environmental performance, economic returns, and social well-being.

Based on the aforementioned policy practice characteristics, systematically examining the mechanism by which green credit subsidy policies affect green total factor productivity holds significant research value. This study focuses on three core issues: Firstly, can this policy tool effectively enhance regional green total factor productivity? Secondly, is its path of action achieved by stimulating green technology innovation in enterprises? Furthermore, do the implementation effects of different pilot regions exhibit spatial heterogeneity? Scientific answers to these questions cannot only improve the theoretical system of green finance policy evaluation but also provide a decision-making basis for optimizing policy transmission mechanisms and promoting the coordinated development of regional green productivity.

## 2. Literature Review

### 2.1. Green Finance: A Research Compendium

In both domestic and international research fields, scholars have shown a dual track trend in exploring green finance: some of the literature focuses on fundamental research on defining policy connotations and evaluating implementation effects, while others specifically focus on theoretical analysis and empirical testing of green credit discount policies. Mehroush et al. [1] proposed that the essence of green finance lies in a dual orientation that aligns financial support with ecological conservation toward a shared direction, and its operational mechanism lies in countries formulating and implementing more targeted policies and green finance to improve environmental performance. Gul et al. [2] emphasized the lubricating effect of the financial system on economic operation, pointing out that green finance policies can reshape the strategic decision-making framework of enterprises, essentially by guiding financial institutions and investor resources, promoting the performance improvement of enterprises in non-financial dimensions such as environmental governance, and ultimately achieving sustainable development goals.

Existing studies have largely focused on the dimensions of “carbon reduction” and industrial upgrading and transformation, examining the institutional impacts and transmission effects generated by ecologically oriented financial instruments. The empirical results of Mirza et al. [3] indicate that the advancement of ecologically oriented credit systems has exerted a significant positive pull on greenhouse gas abatement efficacy, and this pull effect is further amplified under the catalysis of clean technology iteration (proxied by the number of environmental patent grants), with central provinces and resource-intensive areas being particularly prominent, thereby confirming the critical value of implementing regionally differentiated governance strategies for the regulation of greenhouse gas emissions. Guo Xiyu [4] points out that the ecologically oriented credit system and the low-greenhouse-gas-emission economy constitute a pattern of mutual empowerment, wherein the expansion of the former can effectively drive the growth of the latter, and in turn provide institutional support for the realization of the nation’s medium- and long-term carbon neutrality strategic vision. Jiang Hongli et al. [5], based on categorical differences in financing instruments, selected eco-friendly loans and environmentally oriented venture capital as their research subjects, constructed a dynamic panel econometric framework for quantitative validation, and confirmed that both types of funding channels exert

a notable compressing effect on greenhouse gas emissions. In addition, the empirical analysis by Gao Jinjie and Zhang Weiwei [6] reveals that the sustainable financing system, through the expansion of clean production industries, steers the restructuring of national economic sectors toward a green direction, with this transmission effect being particularly pronounced in the eastern coastal regions. Li et al. [7] further point out that the institutional exploration of the low-carbon credit reform pilot zones, via two mediating pathways—namely clean technology iteration and industrial layout optimization—has significantly driven greenhouse gas reduction at the local level, and this inference remains robust across multiple model specifications.

Regarding the micro-level transmission mechanisms of sustainable financing instruments, the academic literature has focused on examining their impact on the operational behavior of deposit-taking financial institutions. Zhang Lin et al. [8] verified that eco-friendly loans make a significant positive contribution to banks' operating performance; He Lingyun et al. [9] further found that the implementation of such credit arrangements can effectively improve financial institutions' return on assets. Meanwhile, some studies have extended the analytical scope to the linkage between the financing system and the real economy. Lalou et al. [10], drawing on panel data from 13 financial institutions in Bangladesh over the period 2013–2022, employed static and dynamic panel models for estimation, revealing that institution-level heterogeneity characteristics and external macroeconomic factors exert significant explanatory power over sustainable credit activities, which in turn transmit to the profit margins of traditional depository institutions (measured by return on assets, return on equity, and net interest margin). The econometric results indicate that, among the variables related to sustainable finance, only the risk oversight functional body under the board of directors exhibits a significant negative coefficient on return on assets, while the number of self-service equipment installations shows a significant positive coefficient on return on equity. The share of eco-oriented credit and the risk oversight functional body exert a significant positive pull on net interest margin, whereas employee training in sustainable finance, self-service equipment coverage, and online service outlets demonstrate a notable constricting effect on net interest margin. With respect to the cost of external funds, Lian Lili [11] points out that environmentally constrained loans significantly raise the debt interest burden of high-emission industries, whereas Cao Yanqiu et al. [12] contend that such credit arrangements can effectively stimulate clean process innovation activities among business entities. Against the broader backdrop of globally coordinated efforts to advance climate governance and sustainable prosperity, eco-oriented credit allocation—as a key institutional arrangement for channeling funds into the clean energy sector—plays an irreplaceable role in the transition toward a low-carbon circular economic paradigm. Based on observational samples spanning 2009 to 2022 and employing heterogeneity identification strategies, Chen et al. [13] found that ecologically oriented credit arrangements have significantly expanded the external debt volume of clean energy business entities while reducing their cost of capital utilization. Moreover, this dual effect exhibits a differentiated pattern depending on the ownership structure of the business entities: state-controlled entities reap greater benefits from the expansion of debt scale, whereas non-state entities gain more pronounced advantages from the reduction in capital costs. Concurrently, the academic community has undertaken systematic investigations into the overall economic spillover effects of sustainable credit, with analytical emphasis placed primarily on the intervention effects of such credit allocation on the structural evolution of national economic sectors. The cumulative findings of Chen Weiguang and Hu Dang [14], Xu Sheng [15], Shao Chuan [16], and other scholars consistently converge on a shared conclusion, namely that ecologically friendly lending exerts a significant driving function in steering industrial hierarchies toward

higher-order progression. The empirical results of Meng et al. [17] indicate that ecologically constrained credit institutions, operating through price-signal transmission and industrial iteration channels, have exerted a significant facilitative effect on the green compliance behaviors of business entities in China's high-emission sectors. Moreover, this effect exhibits dynamic evolutionary patterns along the marginal dimension, accompanied by a certain degree of policy response lag. Qian Shuitun et al. [18], building upon this foundation, further elucidate that the intervention of sustainable credit in the layout of national economic sectors is achieved through the synergistic operation of multiple channels, including capital accumulation, investment flow guidance, information asymmetry mitigation, industrial chain convergence, and risk diversification allocation. Li Yu et al. [19], employing a two-way fixed effects estimation framework for parameter identification, find that ecologically friendly lending exerts a significant positive driver on the upward tier-shifting within the industrial sector, yet displays a certain constraining tendency on the release of developmental momentum in the service sector. In addition, the empirical analysis of Xie Tingting and Liu Jinhua [20] further confirms a significant positive statistical association between eco-friendly lending and the upward progression of industrial hierarchies. He Zhichan et al. [21], employing evolutionary game-theoretic analytical tools, provide a theoretical characterization of the strategic choice logic and behavioral evolution trajectories of micro-level actors within the institutional framework of green credit interest subsidy schemes. Drawing on observational data from firms listed on the Shanghai and Shenzhen A-share markets over the period 2008–2022, and integrating a multi-period difference-in-differences identification strategy with mediation-effect testing procedures, they systematically evaluate the intervention effects of green credit subsidy programs on the clean-transition processes of business entities, as well as the corresponding transmission pathways. Extending the observation window to 2023, Gao Yuqiang et al. [22] take listed firms as their analytical units and employ an incremental difference-in-differences estimator to empirically investigate the incentive effects and underlying mechanisms of green credit subsidy schemes in enhancing corporate ecological information transparency. The findings reported by Li et al. [23] indicate that sustainable credit, operating through the mediating channel of R&D and innovation capacity development, has exerted a significant propulsive effect on the optimization and upgrading of China's national economic sectoral architecture, with the intensity of this propulsive effect exhibiting a distinctly differentiated spatial pattern across geographical regions.

## 2.2. Research on Green Total Factor Productivity

In the field of quantitative assessment of ecologically integrated output efficiency, Repetto et al. [24] pointed out that traditional output efficiency accounting paradigms, due to their failure to incorporate ecological maintenance dimensions, are unable to accurately measure comprehensive factor utilization performance. Liu et al. [25], drawing on panel data from 278 prefecture-level administrative units in China over the period 2001–2022, introduced non-desirable by-products—such as pollution load and insufficient resource conversion rates—into the SBM-DEA analytical framework to numerically measure ecologically integrated output efficiency, and on this basis, explored the impact mechanisms and transmission pathways through which climate system evolution affects fluctuations in this efficiency measure. Relevant scholarly explorations within the domestic academic community have proceeded primarily along three pathways: first, from the spatial delineation perspective, researchers have mostly conducted quantitative analyses based on data units at the provincial or prefectural-city scale. For example, Yu Yishan and Weiping [26], employing an analytical scheme that couples a super-efficiency non-radial measurement framework with the global Malmquist–Luenberger productivity index, conducted a quantitative assessment of the ecologically integrated output efficiency of 283

prefecture-level administrative units in China. Their results indicate that process innovation constitutes the primary driving force behind the sustained upward trajectory of this efficiency measure. At the level of industrial categories and subsectoral divisions, existing research has largely concentrated on the measurement of ecologically integrated efficiency within specific industries. Zhang Zeyi and Han Dongzhen [27], taking the manufacturing and processing industry as their analytical vehicle, carried out a systematic quantitative accounting of ecologically integrated efficiency in this sector in China, thereby providing an important benchmark reference for subsequent related inquiries. At the micro-entity level, some scholars have also scaled their research focus down to the operational unit. Gong Xinshu and Du Jiangyun [28], employing a super-efficiency non-radial measurement model that incorporates non-desirable outputs, conducted a systematic quantification of the ecologically integrated efficiency of listed companies in high-environmental-load industries within China's Shanghai and Shenzhen A-share markets, thereby opening up a new analytical pathway for micro-econometric research on ecological efficiency.

The identification of driving factors for ecologically integrated output efficiency has emerged as a core research question of sustained scholarly attention. To date, existing studies have yet to reach a consensus regarding the direction of the relationship between environmental regulatory intensity and this efficiency measure. Some scholars subscribe to the "innovation compensation" theoretical hypothesis, contending that environmental regulation can exert a positive pull on ecologically integrated output efficiency by compelling business entities to undertake technological upgrading. The empirical work of Yuan Yijun and Xie Ronghui [29], Liu Hewang and Zuo Wenting [30], among others, demonstrates that moderate environmental constraints generate significant efficiency-enhancing effects on ecologically integrated output efficiency. However, other scholars have raised counterarguments, suggesting that environmental regulation may impose adverse pressures on this efficiency measure. Huang Qinghua [31] and colleagues point out that once environmental standards exceed a certain threshold, they may induce an increase in enterprise evasive emission behaviors, thereby weighing down ecologically integrated output efficiency. Furthermore, the independent analysis by Wu Gezhi and You Daming [32] further reveals that, observed from the national macro scale, the intensity of environmental regulatory enforcement may exert a crowding-out effect on technological iteration, thereby impeding the improvement of ecologically integrated output efficiency. Regarding the direction of the relationship between financial system evolution and ecologically integrated output efficiency, the academic community has likewise failed to reach a consensus. Zhang Fan [33] and Wang Wei [34] contend that the deepening and expansion of the financial system exert a significant positive pull on this efficiency measure. Wang Xiaoteng [35] and colleagues, taking the cross-national panel data of economies along the Belt and Road as their analytical subject, empirically examined the statistical relationship between financial development and ecologically integrated output efficiency, with results indicating that both the depth of financial penetration and the rationality of financing structure are positively associated with this efficiency, while financial operational efficiency is negatively associated with it. However, Ge Pengfei [36] and others, based on sample data from 42 Belt and Road countries over the period 1995–2012, found that financial system evolution did not produce a significant driving effect on the enhancement of ecologically integrated output efficiency. Yan et al. [37] point out that environmental regulation can promote the growth of ecologically integrated output efficiency in the industrial sector through such mediating channels as innovation capacity cultivation. However, price-signal-based regulatory instruments prove less effective in greenhouse gas compression, performing better in regions with abundant financial resources while exhibiting constraining effects in regions with weak financial support.

### 2.3. *The Impact of Green Finance on Green Total Factor Productivity*

Institutional arrangements aimed at promoting the improvement of ecologically integrated output efficiency can generally be categorized into three types: first, market-incentive instruments, including pollution taxes and emissions trading mechanisms, which leverage price signals to drive pollution abatement and technological innovation; second, administrative directive controls, which employ mandatory standards to guide industrial hierarchies toward higher-order transitions; and third, eco-friendly credit subsidy arrangements, designed to reduce the capital acquisition costs of clean production projects. This study anchors its analytical focus on the third type of institution—namely, eco-friendly credit subsidies—and their effect on this efficiency measure. As China's economy enters a new cycle of quality-led growth, sustainable finance has risen to become a key direction in the structural restructuring of the financial system. The academic community has conducted extensive explorations around the intrinsic linkages between sustainable finance and economic operations, among which the directional effect of sustainable finance on ecologically integrated output efficiency has presently coalesced into three representative perspectives. The articulation and contestation of these perspectives have not only deepened our systematic understanding of the economic effects of sustainable finance but also provided important theoretical support and decision-making references for the refined design and effective implementation of future policy frameworks. First, the mainstream research position holds that sustainable finance makes a significant positive contribution to ecologically integrated output efficiency. For example, the empirical analysis by Xiong Yunbiao et al. [38] demonstrates that sustainable finance can significantly elevate ecologically integrated output efficiency at the national aggregate level, with this effect exhibiting notable differentiation across geographical dimensions, among which the western region reaps the most prominent gains. Xie Dongjiang and Hu Shihua [39] also endorse this judgment, pointing out that sustainable finance exerts a positive driving force on ecologically integrated output efficiency, yet its regional differentiation manifests as the eastern and central regions benefiting to a greater extent than the western region. Wang et al. [40] further find that ecologically oriented credit allocation, as a critical financing adjustment instrument, can significantly improve the ecologically integrated output efficiency of the industrial sector through two transmission pathways—namely, industrial hierarchy upgrading and clean technology R&D—and that this promoting effect continues to amplify with the expansion of credit allocation scale, the accumulation of labor skill stocks, and the intensification of technological R&D efforts, with this trend becoming particularly pronounced after 2016; however, this effect holds only for the eastern region of China and fails to pass significance tests in the central and western regions. Secondly, some scholars argue that the relationship between sustainable finance and ecologically integrated output efficiency does not follow a simple linear pattern. Yin Zibo et al. [41], by introducing a spatial autoregressive panel model into their analysis, identify a “first-decline-then-rise” trajectory between the level of sustainable finance development and ecologically integrated output efficiency: in the short term, it may exert a certain drag on efficiency, but in the long run, once the development level crosses a certain critical threshold, it turns into a significant promoting force. Thirdly, some scholars have shifted their analytical focus down to the business-entity level to examine the intervention effects of sustainable finance institutions on the ecologically integrated output efficiency of micro-level units. The research findings of Zhang Yongliang and Hui Bingjie [42] indicate that the implementation of sustainable finance policies has exerted a significant negative impact on the ecologically integrated output efficiency of high-environmental-burden enterprises. In addition, some studies have approached the issue from the perspective of spatial transmission effects, examining the indirect effects of sustainable finance on ecologically integrated output efficiency.

Overall, the existing literature has formed a relatively rich body of knowledge regarding the relationship between sustainable finance and ecologically integrated output efficiency, yet there remain several analytical blind spots worthy of further exploration. This study aims to investigate the direction and transmission pathways through which the ecological loan interest compensation mechanism—institutionally underpinned by the joint operation of administrative departments and market intermediary organizations—affects this efficiency indicator. The marginal contributions of this study are concentrated in the following three dimensions. First, while most prior work has assessed the impact of sustainable finance on the ecologically integrated output efficiency of business units from a unidimensional perspective, this study attempts to shift the analytical paradigm by foregrounding the interactive and synergistic features between public authority entities and market capital suppliers in sustainable finance practice. Operationally, we treat the staggered timing of the ecological loan interest compensation mechanism's phased implementation across various administrative regions in China since 2017 as an exogenous source of policy shocks, thereby constructing a foundation for causal inference between policy coordination and ecologically integrated output efficiency. Second, at the identification strategy level, this study introduces a multi-period difference-in-differences estimation framework to identify the causal effects of policy shocks. Compared with conventional ordinary least squares estimation, the multi-period difference-in-differences framework offers significant advantages in eliminating unobservable time-varying confounders, thereby effectively enhancing the internal validity and statistical precision of the estimation results. Third, given the current scarcity of causal evidence on the ecological loan compensation mechanism, this study directly links the institutional coordination variable with ecologically integrated output efficiency, thereby supplementing this research lineage with urgently needed empirical material and evidentiary chains.

### 3. Mechanism Analysis and Research Hypothesis

#### 3.1. *The Impact of Green Credit Subsidy on GTFP*

The insufficiency of external capital accessibility constitutes the most critical institutional constraint in the process of advancing ecologically integrated output efficiency. In the Chinese market environment dominated by the bank credit financing system, sustained and stable funding supply plays a decisive role in improving green production efficiency. When facing severe credit tightening, enterprises often adjust their resource allocation strategies, reduce resource investment in green industries and projects, and instead tilt resources towards high-energy-consuming areas to optimize asset allocation efficiency. Specifically, financial constraints significantly amplify the operational risks in technology research and development, product manufacturing, and market promotion, forcing the liquidity-limited enterprises to prioritize investing their limited funds in operations, maintenance, and debt repayment, resulting in insufficient momentum for improving green production efficiency.

The transmission of the ecological loan interest compensation system to ecologically integrated output efficiency is primarily realized through the following three channels of action: firstly, based on the long-term value orientation of capital allocation theory, this policy uses incentive tools such as interest subsidies and special loans to lower the entry threshold for green projects. By guiding capital to focus on the long-term return characteristics of green industries, it not only promotes the construction of sustainable development strategic frameworks for enterprises but also facilitates the accumulation of funds in areas such as green technology research and development and the circular economy. This directional capital flow not only activates the development of green industries but also forms a reverse transformation mechanism by restricting the supply of high-energy-consuming industrial factors, driving the improvement of green production efficiency in a

dual way. Secondly, this policy deepens the strategic synergy between green finance and the real economy. Market-oriented funding providers, by virtue of differentiated service portfolios spanning the full spectrum of operational activities, furnish capacity-building support for the low-carbon reconfiguration of the industrial system, and in so doing establish a novel governance architecture characterized by efficient capital–industry integration, thereby markedly enhancing the institutional framework’s leverage in promoting clean production performance improvements. Once again, the clear market signals conveyed by policies stimulate the endogenous driving force of green transformation in enterprises. In order to obtain valuation premiums and market reputation in the capital market, enterprises actively strengthen the construction of green production systems, optimize production efficiency to improve business quality, and thus form a sustainable competitive green brand value. Based on the foregoing discussion, this paper puts forward the following empirical hypothesis:

**H<sub>1</sub>.** *Implementing green credit subsidy policies can effectively improve GTFP.*

### 3.2. Influence Mechanism

In terms of the economic aggregate, China has firmly secured its position as the world’s second-largest economy. Yet beneath the surface of rapid growth lies the persistent specter of excessive natural capital depletion. The expansionary development trajectory, characterized by intensive resource inputs, has led to a continuous narrowing of marginal returns on the output side. To achieve a leap in production efficiency, it is imperative to rely on process innovation and technological advancement. As an institutional instrument for implementing the national sustainable finance strategy, the ecologically oriented loan interest subsidy scheme has already generated significant leading and spill-over effects at the macro level. Through institutional designs such as differentiated fiscal leverage and loss-sharing mechanisms, it guides the precise injection of credit resources into clean production sectors, infuses the entire national economic system with institutional momentum for low-carbon transition, and in this process, explores a new development pathway that balances economic growth performance with environmental quality.

The sustainable credit subsidy system can stimulate the innovation momentum of economic entities through four channels: resource security, financing pathway expansion, information exchange, and green pressure transmission. First, this system can effectively strengthen the funding support for the R&D and experimentation stage. Clean process R&D is inherently capital-intensive and characterized by long payback cycles, and the slow commercialization process further leads to insufficient cash flow stability. The targeted subsidy arrangements, through tools such as interest compensation and loss sharing, resolve the liquidity bottlenecks faced by innovation entities and reduce the sunk costs incurred during the experimentation and exploration process. Second, it establishes multi-tiered capital access channels. Through structural instruments such as green debt credit enhancement arrangements and industrial guidance funds, it leverages private capital to converge toward clean process development, alleviating the external financing bottlenecks faced by asset-light technology entities under conditions of insufficient collateral. Third, it builds platforms for information exchange and collaborative R&D. Relying on institutional guidance, it establishes a linkage framework among academic institutions, R&D entities, and production enterprises, and through platforms such as cross-border qualification training and technology transfer hubs, cultivates compound-skilled human capital, generating positive externalities from the cross-entity flow of process knowledge. Fourth, it establishes a green pressure transmission mechanism. By strengthening environmental data disclosure norms and financing review standards, it imposes external con-

straints on enterprises, compelling them to build a full-product-lifecycle ecological governance framework, thereby driving the low-carbon transformation of manufacturing processes and the tiered upgrading of clean technologies.

Process innovation exerts a significant driving effect on ecologically integrated output efficiency. First, Romer [43] embedded R&D activities and imperfect market competition structures into the technological change module of the growth analytical framework, and his endogenous growth theory identifies technological upgrading as the fundamental power source underpinning long-term stable economic performance. Through engineering-level breakthroughs such as process optimization, improved resource utilization efficiency, and emission reduction, it is possible to achieve compatibility between output efficiency gains and environmental burden reduction. Ecologically oriented subsidy arrangements, through a triple transmission mechanism of capital provision, regulatory guidance, and skill accumulation, reduce the sunk costs incurred by business entities in their exploration of clean processes and accelerate the transfer of environmentally friendly technologies from the laboratory to the production floor. Second, the logic of “creative destruction” as revealed by Schumpeter explains the reshaping function of technological generational succession on the industrial landscape. The widespread diffusion of highly efficient clean processes will gradually phase out obsolete, energy-intensive installations, redirect productive factors toward low-emission spaces, and drive the transition of growth momentum from quantitative factor accumulation to efficiency-oriented composite factors, ultimately forming a mutually reinforcing closed loop between economic growth and environmental quality. Finally, there exist significant theoretical divisions regarding the economic consequences of green credit instruments as environmental regulatory tools. The neoclassical tradition emphasizes that environmental constraints will raise the institutional compliance expenditures of business entities and weaken their market competitiveness. By contrast, the Porter proposition, from a dynamic efficiency perspective, argues that reasonable environmental pressure can force enterprises to implement innovation-compensation strategies, secure first-mover advantages through clean technology patent portfolios, and ultimately reap the combined dividends of cost reduction, efficiency enhancement, and ecological improvement. Based on the above reasoning, this study proposes the following theoretically testable proposition:

**H<sub>2</sub>.** *Green credit subsidy policies can promote the improvement of GTFP through technological innovation.*

The sustainable finance system, through a dual-action pathway, drives financial intermediaries to enhance their capacity for ecological risk identification and management, while structurally optimizing their operational decision-making frameworks, thereby effectively expanding external funding channels for business entities transitioning toward low-emission models. In pilot regions where the system is ahead of the curve, administrative authorities, relying on public fiscal compensation mechanisms, provide implicit credit support by covering all or part of the interest costs of ecological project financing, significantly narrowing the potential loss boundaries of capital suppliers. This institutional arrangement effectively guides depository institutions to shift their credit focus toward clean production sectors, promotes the sustained expansion of eco-friendly loan balances, and systematically improves the external funding accessibility of clean product manufacturers. Taking the policy practice of Shenzhen as an example, the local fiscal authorities provide proportional premium subsidies to business entities that purchase ecological damage liability insurance. Enterprises can then leverage the implicit credit endorsement embedded in the fiscal compensation to obtain corresponding green financing services

from capital suppliers. Based on the above reasoning, this study proposes the following theoretically testable proposition:

**H3.** *The green credit subsidy can promote the improvement of FTFP by expanding green credit.*

The theory of financial resources indicates that financial resources possess both the scarcity attributes of general production factors and the guidance and allocation functions embedded at the strategic design level. The scarcity of ecologically oriented credit allocation is manifested in the green compliance review systems implemented by financial intermediaries, while its macro-guidance function is reflected in the institutional practice whereby administrative authorities, leveraging eco-credit policy instruments, channel public funds toward environmentally friendly projects, thereby driving the coordinated advancement of socioeconomic growth and ecological preservation. Wang and Wang point out that ecologically oriented credit allocation, as a key policy lever for catalyzing industrial transformation, can enhance resource conversion efficiency, stimulate green growth potential, and provide a stable funding base for long-term sustainable development by directing investment toward the environmental protection sector. This differentiated subsidy system, through the effective coupling of macro-institutional frameworks and grassroots operational practices, both embodies the principle of intensive utilization of scarce financial resources and reflects the strategic coordination capacity at the national macro level. Under the constraint of limited total resource supply, this system redirects public funds from traditional energy-intensive sectors toward substantive environmental protection projects, thereby driving the optimization of factor allocation structures and the evolutionary upgrading of industrial organizational forms. Environmental technology firms, in order to secure long-term funding support, proactively guide their operational systems toward low-carbon, high-value-added trajectories, thereby capturing the growth dividends arising from structural transformation and driving the sustained upward movement of comprehensive factor productivity. Based on the above reasoning, this study proposes the following theoretically testable proposition:

**H4.** *Green credit subsidy policies can promote the improvement of GTFP by promoting industrial upgrading.*

## 4. Empirical Design

### 4.1. Research Methods and Models

#### 4.1.1. DID Differential Model

This article takes the introduction of green credit subsidy policies in various regions as a natural experiment to test the policy effect on GTFP. This article sets model (1) as follows:

$$GTFP_{it} = \beta_0 + \beta_1 Post_t \times Treat_i + \beta_2 Control_{it} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Among them,  $GTFP_{it}$  refers to the GTFP of a certain region  $i$  in year  $t$ , and  $Post_t$  represents a time dummy variable; when the province implemented the green credit subsidy that year, the value is 1.  $Treat_i$  represents the province dummy variable of whether a certain province has implemented green credit subsidy policies.  $\beta_0$  refers to the constant term, and  $\beta_1$  represents the estimation coefficient, which is the focus of the multi-temporal DID benchmark regression model in this article.  $Control_{it}$  represents a series of control variables selected in this article,  $\mu_i$  reflect individual fixed effects,  $\lambda_t$  reflects the fixed time effect, and  $\varepsilon_{i,t}$  is the random error term of the model.

#### 4.1.2. Mediation Effect Model

To test whether the green credit subsidy policy affects GTFP through technological innovation, green credit, and industrial upgrading channels, this paper constructs models (2)–(7) based on model (1) and draws on the method of Jiang Ting (2022) [44] to test the mediating effect.

$$\text{Tech}_{it} = \alpha_0 + \alpha_1 \text{Time}_t \times \text{Treat}_i + \alpha_2 \text{Control}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (2)$$

$$\text{Credit}_{it} = \alpha_0 + \alpha_1 \text{Time}_t \times \text{Treat}_i + \alpha_2 \text{Control}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (3)$$

$$\text{Promotion}_{it} = \alpha_0 + \alpha_1 \text{Time}_t \times \text{Treat}_i + \alpha_2 \text{Control}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (4)$$

$$\text{GTFP}_{it} = \beta_0 + \beta_1 \text{Time}_t \times \text{Treat}_i + \beta_2 \text{Control}_{it} + \beta_3 \text{Tech}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (5)$$

$$\text{GTFP}_{it} = \beta_0 + \beta_1 \text{Time}_t \times \text{Treat}_i + \beta_2 \text{Control}_{it} + \beta_3 \text{Credit}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (6)$$

$$\text{GTFP}_{it} = \beta_0 + \beta_1 \text{Time}_t \times \text{Treat}_i + \beta_2 \text{Control}_{it} + \beta_3 \text{Promotion}_{it} + \mu_i + \lambda_i + \varepsilon_{it} \quad (7)$$

#### 4.1.3. SCM Integrated Control Method

The integrated control method is another econometric approach for estimating policy effects, suitable for situations where there is a lack of appropriate control groups.

The synthetic control method is another econometric approach for estimating policy effects, suitable for situations where there is a lack of appropriate control groups. The core logic is to construct a similar control group for the processing group and evaluate the policy effect by comparing the actual results of the processing group with the results of the synthesized control group. This study starts with the implementation of the first batch of green financial credit subsidy policies in 2017, and includes 30 provincial units (except Xizang, Taiwan, Hong Kong, and Macao) in the scope of analysis. Hebei, Xinjiang, Chongqing, Anhui, Beijing, and Hunan were designated as experimental groups, while the remaining 24 provincial-level units were designated as control groups. Set the model (8) as follows:

$$\beta_{i,t} = \text{GTFPI}_{i,t} - \text{GTFPN}_{i,t} \quad (8)$$

Among them, for province  $i$  that was not affected by the green finance credit subsidy policy during period  $t$ , its green total factor productivity can be expressed as  $\text{GTFPN}_{i,t}$ , and  $\text{GTFPI}_{i,t}$  represents the GTFP when affected by the green finance credit subsidy policy. For the pilot areas, this article uses  $\beta_{i,t}$  to represent the intervention effect of green finance credit subsidy policies.

#### 4.2. Variable Design

##### 4.2.1. Explained Variable

This article takes green total factor productivity (GTFP) as the core research object of the dependent variable. Tone (2001) [45] constructed an SBM model with unexpected inputs (based on DEA), whose slack variables intuitively reflect the degree of DMU's over input or under output. The Malmquist index measures the growth of total factor productivity (TFP) and reflects the dynamic changes in efficiency evaluation across time periods. The Malmquist–Luenberger (ML) index is an extension that takes into account unexpected outputs. This index design aims to overcome the bottleneck of linear programming without feasible solutions when calculating ML indices. The global Malmquist–Luenberger (GML) index compensates for the shortcomings of traditional measurement methods by incorporating production units into a global reference set. In summary, this article uses

the SBMI-GML method under the global production technology set to measure the provincial GTFP, and calculates the input and output indicators involved, as shown in Table 1.

The input indicators in this article include labor, capital, and energy inputs, which are measured using the method proposed by Shi Daimin and Shi Xiaoyan (2022) [46]. Among them, labor input is measured by the number of urban employed people, and capital input is measured by the perpetual inventory method. The calculation formula is  $K_t = K_{t-1}(1 - \delta_t) + I_t$ , where the depreciation ratio  $\delta_t$  refers to the previous literature as 9.6%,  $I_t$  representing the total fixed assets, and the standard coal usage represents energy input. The output indicators cover both expected output and undesirable output, with unexpected output referring to the pollutants emitted by residents' daily lives. This article refers to the method proposed by Li Bo et al. (2002) [47] to measure output indicators.

**Table 1.** Calculation of green total factor productivity.

| Category         | Variable           | Variable Declaration                    | Unit                         |
|------------------|--------------------|-----------------------------------------|------------------------------|
| Input Indicator  | Labor input        | Year-end employment of urban workers    | Thousands of people          |
|                  | Energy input       | Total energy consumption                | 10,000 tons of standard coal |
|                  | Capital input      | Using 2004 as the base year             | A hundred million yuan       |
| Output Indicator | Expected output    | Gross domestic product of each province | A hundred million yuan       |
|                  | Undesirable output | Industrial wastewater                   | 10 thousand tons             |
|                  |                    | Industrial fumes                        | Ton                          |
|                  |                    | Industrial sulfur dioxide               | Ton                          |

#### 4.2.2. Explanatory Variables

The explanatory variable in this article is the interaction term obtained by multiplying the time dummy variable by the province dummy variable. (Time  $\times$  **Treat**).

#### 4.2.3. Control Variables and Mediator Variables

Referring to previous research, this article sets seven control variables: the level of national economic development (GDP) represents per capita GDP; the urban population size indicator represents the proportion of urban population to the total population; the financial scale (Fin) indicator represents the ratio of the added value of the financial industry to the regional GDP; the scale of fiscal expenditure (Gov) indicator represents the proportion of total fiscal expenditure to the GDP of each province; the scale of human capital (Hau) represents the ratio of the number of undergraduate and junior college students in higher education to the total population of each province; public transportation infrastructure (Bus) represents the number of buses per hundred people; and the proportion of the secondary industry (Sip) represents the proportion of the secondary industry in the overall industry outcome. This article also sets three mediating variables: Technological innovation (Tech) represents the number of green patent applications authorized by various provinces and cities (in thousands) [48]; green credit represents the ratio of interest payments in the environmental protection industry in different regions to the total interest payments in each industry, and its annual average is taken; promotion represents the ratio of green industries to GDP by region.

#### 4.3. Data Sources and Descriptive Statistics of Variables

The data for this study are sourced from the China Statistical Yearbook and the EPS database over the years. Table 2 reports the descriptive statistics of the variables used in this study. The maximum value of GTFP is 5.18, the minimum value is 0.68, and the standard deviation is about 0.82, indicating significant differences in green total factor productivity among different regions.

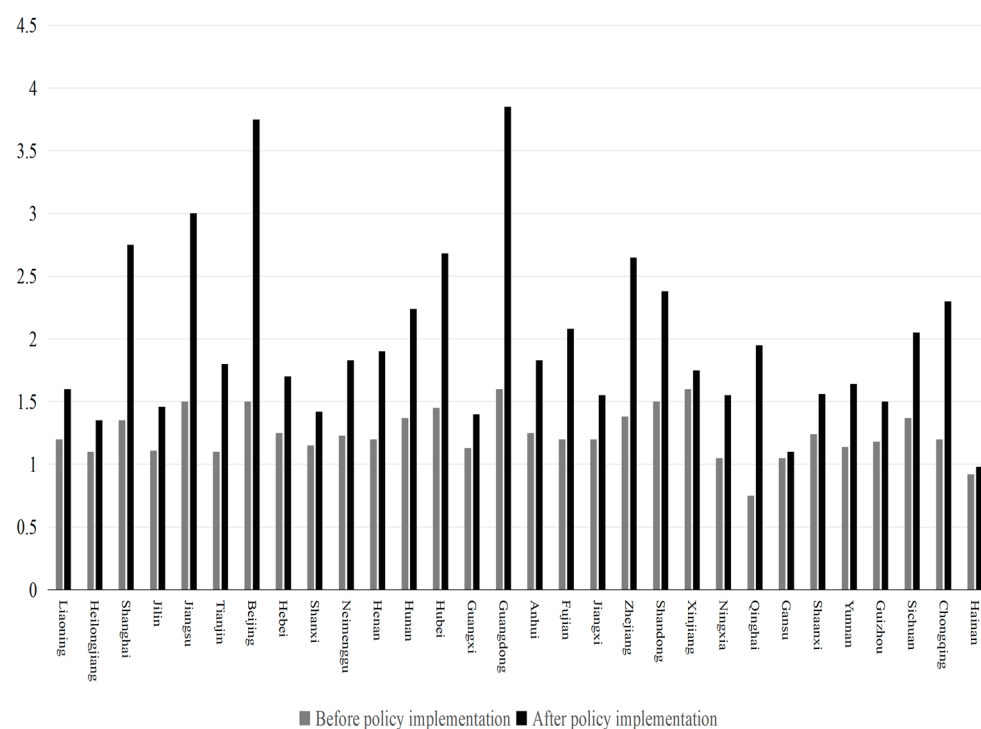
Table 2. Descriptive statistics.

| Variable                             | Indicator Name | Observations | Mean  | Standard Deviation | Min   | Max   |
|--------------------------------------|----------------|--------------|-------|--------------------|-------|-------|
| Green total factor productivity      | GTFP           | 540          | 1.36  | 0.82               | 0.68  | 5.18  |
| National economic development level  | GDP            | 540          | 4.68  | 2.88               | 0.48  | 16.76 |
| Financial scale                      | Fin            | 540          | 0.08  | 0.04               | 0.01  | 0.21  |
| Proportion of the secondary industry | Sip            | 540          | 46.68 | 8.78               | 14.80 | 60.52 |
| Public transportation infrastructure | Bus            | 540          | 0.96  | 0.48               | 0.28  | 2.36  |
| Fiscal expenditure scale             | Gov            | 540          | 0.24  | 0.12               | 0.08  | 0.78  |
| Urban population size                | Urban          | 540          | 55.78 | 14.16              | 25.88 | 88.64 |
| Scale of human capital               | Hau            | 540          | 8.36  | 5.48               | 0.36  | 50.64 |
| Green credit                         | Credit         | 540          | 0.25  | 0.35               | 0.01  | 1.68  |
| Industrial upgrading                 | Promotion      | 540          | 0.04  | 0.08               | 0     | 0.48  |
| Technological innovation             | Tech           | 540          | 6.36  | 10.04              | 2.45  | 56.32 |

## 5. Empirical Results and Analysis

### 5.1. Measurement of Green Total Factor Productivity

GML is used to calculate the growth of GTFP, with a base period GTFP of 1, and the GTFP values for each year are obtained through cumulative multiplication. Given the large sample size, this study selected data before and after the implementation of financial credit subsidy policies from 2005 to 2022, and calculated the geometric mean of GTFP in 30 provinces (cities, autonomous regions) in China to reflect its changes (see Figure 1). The results showed that the GTFP in Guangdong and Beijing had the largest changes before and after policy implementation, followed closely by Jiangsu, Zhejiang, and Shanghai. Overall, both the experimental group and the control group showed a significant upward trend in green total factor productivity.



**Figure 1.** Geometric mean bar chart of GTFP before and after the implementation of policies in 30 provinces, municipalities, and autonomous regions in China from 2005 to 2022.

### 5.2. Benchmark Regression

After verifying the parallel trend hypothesis, this paper applies a difference in differences model to analyze the impact of green credit subsidy policies on GTFP in various regions.

The benchmark regression results are shown in Table 3. After considering the issue of sequence correlation and controlling for individual fixed effects, time fixed effects, and provincial fixed effects, Model (1) reported the regression results without controlling variables. Compared with provinces that did not implement green credit subsidy policies, i.e., provinces that were not affected by green credit subsidy policies, the GTFP of provinces that implemented policies increased by 0.08, and was significant at the 5% significance level. This indicates that provinces with green credit subsidy policies will increase their green total factor productivity by 0.08 that year. After controlling for variables such as economic development level, education level, and infrastructure level at the provincial level, the regression coefficient of the core explanatory variable is significantly 0.12, and significant at the 1% significance level. This indicates that provinces with green credit subsidy policies will see a 0.12 increase in GTFP that year. This indicates that the green credit subsidy policy can, to some extent, help improve the level of GTFP.

Therefore, this article assumes that  $H_1$  is preliminarily valid.

**Table 3.** Benchmark regression results.

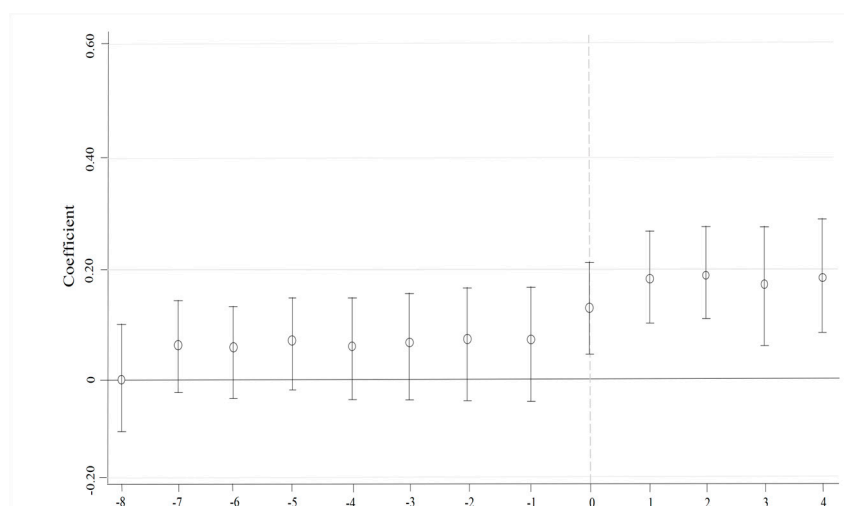
| Variable                 | (1)                | (2)                  |
|--------------------------|--------------------|----------------------|
|                          | GTFP               | GTFP                 |
| <i>Time × Treat</i>      | 0.28 **<br>(2.34)  | 0.36 ***<br>(3.40)   |
| <i>GDP</i>               |                    | 0.24 ***<br>(3.84)   |
| <i>Hau</i>               |                    | 0.03 ***<br>(4.67)   |
| <i>Gov</i>               |                    | −0.13<br>(0.93)      |
| <i>Urban</i>             |                    | −0.02 **<br>(−2.26)  |
| <i>Sip</i>               |                    | −0.02<br>(−0.82)     |
| <i>Fin</i>               |                    | −4.64 ***<br>(−5.32) |
| <i>Bus</i>               |                    | 0.07<br>(1.62)       |
| Constant                 | 1.35 ***<br>(4.71) | 1.26 ***<br>(3.95)   |
| Individual fixed effects | YES                | YES                  |
| Time fixed effect        | YES                | YES                  |
| Observation numbers      | 556                | 556                  |
| $R^2$                    | 0.64               | 0.74                 |

Note: \*\*\*, \*\* are significance levels of 1% and 5%, respectively.

### 5.3. Parallel Trend Test

The application premise of the DID model is through parallel trend testing, which means that before policy implementation, the GTFP change trend of the experimental group (provinces implementing green credit policies) needs to be consistent with that of

the control group (provinces not implementing policies). This article focuses on the analysis of the first three periods and the second three periods of the implementation of green credit policies. Using 2017 as the base year, exclude data from 2016 to avoid multicollinearity issues. Figure 2 shows the regression results of the parallel trend test: before policy implementation, the experimental group and the control group had similar trends in changes; after the implementation of the policy, significant differences were observed between the two, with the 95% confidence intervals of the regression coefficients both above the zero level. This result meets the requirements of the parallel trend hypothesis.



**Figure 2.** Parallel trend test results.

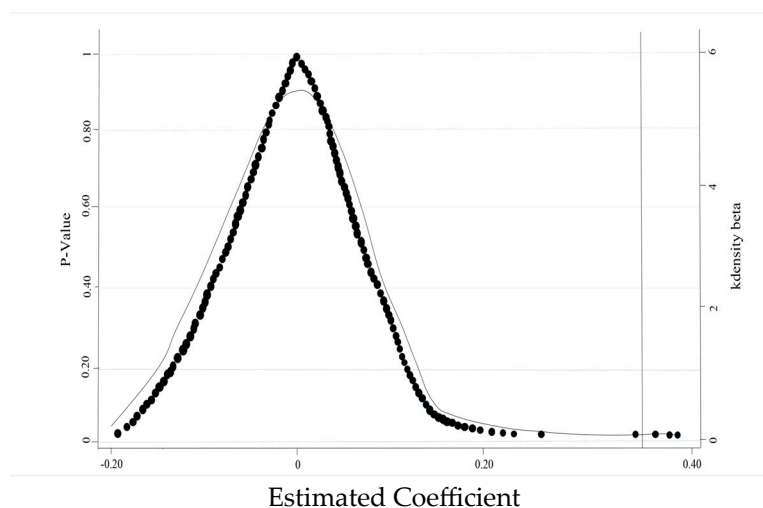
#### 5.4. Robustness Test and Endogeneity Test

##### 5.4.1. Placebo Test

To verify the robustness of the empirical results, this study randomized the treatment group by conducting 500 random samplings of the treatment group variables, including all provinces, using the same control variables and fixed effects. Then, we drew a coefficient distribution chart based on the sampling results (Figure 3). Observation shows that the distribution of random coefficients exhibits a normal feature with a mean of 0, further verifying the randomness. In 500 samples, the vast majority of regression coefficients were below the baseline value, with only three results exceeding the baseline value. This indicates that there is no serious problem of omitted variables in the model, and the likelihood of empirical results being affected by random interference is low. The placebo test passed, supporting hypothesis H1.

##### 5.4.2. Reduce the Time Window

To conduct robustness testing, this article adopted a strategy of reducing the sample size. Given that China launched the first batch of low-carbon city pilot projects in 2010, in order to eliminate external interference from other policies during the same period, this study limited the sample time window to the period from 2010 to 2022, excluded data from 2005 to 2009, and re-regressed. The regression results (Table 4) show that the estimated coefficient of the core explanatory variable is 0.32 and significant at the 1% statistical level. This once again confirms the robustness of the benchmark regression conclusion.



**Figure 3.** Results of placebo test. (Line represents P-Value, dotted line represents kdensity beta).

**Table 4.** Robustness test after reducing the time window.

| Variable                 | (1)                | (2)                  |
|--------------------------|--------------------|----------------------|
|                          | GTFP               | GTFP                 |
| <i>Time × Treat</i>      | 0.23 **<br>(2.26)  | 0.32 ***<br>(4.28)   |
| <i>GDP</i>               |                    | 0.36 ***<br>(4.25)   |
| <i>Hau</i>               |                    | 0.02 **<br>(2.32)    |
| <i>Gov</i>               |                    | −0.13<br>(1.27)      |
| <i>Urban</i>             |                    | −0.04 **<br>(−2.31)  |
| <i>Sip</i>               |                    | −0.04<br>(−0.94)     |
| <i>Fin</i>               |                    | −3.45 ***<br>(−5.68) |
| <i>Bus</i>               |                    | 0.08<br>(1.26)       |
| Constant                 | 1.78 ***<br>(4.56) | 1.63 ***<br>(4.82)   |
| Individual fixed effects | YES                | YES                  |
| Time fixed effect        | YES                | YES                  |
| Observation numbers      | 390                | 390                  |
| $R^2$                    | 0.62               | 0.67                 |

Note: \*\*\*, \*\* are significance levels of 1% and 5%, respectively.

#### 5.4.3. Change the Dependent Variable

To enhance the robustness of the empirical regression results, this paper refers to the ML index method to measure the provincial GTFP, and calculates the input and output indicators as shown in Table 1. Substituting model (1) for re-estimation, Table 5 (2) shows that the regression results remain unchanged.

**Table 5.** Other robustness tests.

| Variable                 | (1)                  | (2)                  | (3)                  |
|--------------------------|----------------------|----------------------|----------------------|
|                          | GTFP                 | TFP                  | GTFP                 |
| <i>Time × Treat</i>      | 0.32 ***<br>(4.28)   | 0.30 ***<br>(3.74)   | 0.29 ***<br>(4.68)   |
| <i>GDP</i>               | 0.36 ***<br>(4.25)   | 0.32 ***<br>(3.82)   | 0.48 ***<br>(5.38)   |
| <i>Hau</i>               | 0.02 **<br>(2.32)    | 0.03 *<br>(1.72)     | 0.04 *<br>(1.87)     |
| <i>Gov</i>               | −0.13<br>(1.27)      | −0.16<br>(1.43)      | −0.19<br>(1.53)      |
| <i>Urban</i>             | −0.04 **<br>(−2.31)  | −0.06 *<br>(−1.84)   | −0.05 *<br>(−1.88)   |
| <i>Sip</i>               | −0.04<br>(−0.94)     | −0.08<br>(−1.52)     | −0.06<br>(−1.38)     |
| <i>Fin</i>               | −3.45 ***<br>(−5.68) | −2.76 ***<br>(−4.72) | −4.56 ***<br>(−5.72) |
| <i>Bus</i>               | 0.08<br>(1.26)       | 0.06<br>(1.60)       | 0.07<br>(1.56)       |
| Constant                 | 1.63 ***<br>(4.82)   | 1.85 ***<br>(3.62)   | 1.46 ***<br>(3.96)   |
| <i>CPI</i>               | NO                   | NO                   | 3.80 ***<br>(4.21)   |
| <i>M2</i>                | NO                   | NO                   | 0.01 *<br>(1.76)     |
| Individual fixed effects | YES                  | YES                  | YES                  |
| Time fixed effect        | YES                  | YES                  | YES                  |
| Observation numbers      | 556                  | 556                  | 556                  |
| <i>R</i> <sup>2</sup>    | 0.67                 | 0.57                 | 0.59                 |

Note: \*\*\*, \*\*, and \* are significance levels of 1%, 5%, and 10%, respectively.

#### 5.4.4. Add Omitted Variables

To ensure the validity of the regression results, this study controlled for potential omitted variables at the macro level, including macro inflation data, CPI, and the natural logarithm of M2 of the total social money supply. As shown in column (3) of Table 2, after considering these factors, the interaction term remains significantly positive, further supporting the robustness of the research results.

#### 5.5. Analysis of Impact Mechanism

Existing research suggests that technological innovation plays a crucial role in promoting the improvement of GTFP. Based on this understanding, this article draws on the “two-step method” proposed by Jiang Ting to test the mediating effects of technological innovation, green credit, and industrial upgrading. Table 6 reports the test results of the mediating effect of technological innovation on channels. Specifically, according to the data in column (3) of Table 6, the estimated coefficient of Tech for technological innovation is 0.04 and significant at the 1% significance level. The estimated coefficient of **Time × Treat** in column (1) is 8.30 and significant at the 1% significance level, indicating the existence of a mediating effect of technological innovation. Hypothesis H2 holds true. According to the data in column (3) of Table 7, the estimated coefficient of green credit is 0.04 and significant at the 1% significance level. The estimated coefficient of **Time × Treat** in column (1) is 0.08 and significant at the 1% significance level, indicating

the existence of a mediating effect of green credit. Hypothesis H3 holds true. According to the data in column (3) of Table 8, the estimated coefficient of industrial upgrading promotion is 0.02, which is significant at the 5% significance level. The estimated coefficient of **Time × Treat** in column (1) is 0.03, which is significant at the 1% significance level, indicating the existence of a mediating effect of technological innovation. Hypothesis H4 holds true.

**Table 6.** Mediating effects of technological innovation.

| Variable                 | (1)                   | (2)                  | (3)                  |
|--------------------------|-----------------------|----------------------|----------------------|
|                          | Tech                  | GTFP                 | GTFP                 |
| <i>Time × Treat</i>      | 8.30 ***<br>(4.65)    |                      | 0.26 ***<br>(5.42)   |
| <i>Tech</i>              |                       | 0.04 ***<br>(3.21)   | 0.04 ***<br>(2.86)   |
| <i>GDP</i>               | 4.54 **<br>(2.21)     | 0.33 ***<br>(5.56)   | 0.46 ***<br>(6.72)   |
| <i>Hau</i>               | 3.67 ***<br>(4.73)    | 0.03 **<br>(2.38)    | 0.04 **<br>(2.42)    |
| <i>Gov</i>               | −1.83<br>(−1.28)      | −0.15<br>(−0.97)     | −0.16<br>(−1.45)     |
| <i>Urban</i>             | −0.47 ***<br>(−5.29)  | −0.05 **<br>(−2.11)  | −0.04 **<br>(−2.37)  |
| <i>Sip</i>               | −0.56<br>(−0.71)      | −0.05<br>(−0.44)     | −0.04<br>(−1.76)     |
| <i>Fin</i>               | −24.52 ***<br>(−3.11) | −2.67 ***<br>(−4.89) | −3.12 ***<br>(−3.92) |
| <i>Bus</i>               | 0.84<br>(0.62)        | 0.07<br>(1.34)       | 0.08<br>(1.78)       |
| Constant                 | 3.14 ***<br>(6.43)    | 1.66 ***<br>(5.63)   | 1.75 ***<br>(3.72)   |
| Individual fixed effects | YES                   | YES                  | YES                  |
| Time fixed effect        | YES                   | YES                  | YES                  |
| Observation numbers      | 556                   | 556                  | 556                  |
| <i>R</i> <sup>2</sup>    | 0.56                  | 0.64                 | 0.77                 |

Note: \*\*\*, \*\* are significance levels of 1% and 5%, respectively.

**Table 7.** Intermediary effect of green credit.

| Variable                 | (1)                | (2)                | (3)                |
|--------------------------|--------------------|--------------------|--------------------|
|                          | Credit             | GTFP               | GTFP               |
| <i>Time × Treat</i>      | 0.08 ***<br>(3.55) |                    | 0.26 ***<br>(4.63) |
| <i>Credit</i>            |                    | 0.05 ***<br>(6.67) | 0.04 ***<br>(3.64) |
| Controls                 | YES                | YES                | YES                |
| Constant                 | 0.33 ***<br>(4.82) | 1.26 ***<br>(3.92) | 1.15 ***<br>(2.88) |
| Individual fixed effects | YES                | YES                | YES                |
| Time fixed effect        | YES                | YES                | YES                |
| Observation numbers      | 556                | 556                | 556                |
| <i>R</i> <sup>2</sup>    | 0.65               | 0.68               | 0.72               |

Note: \*\*\* is significance levels of 1%.

**Table 8.** Intermediary effects of industrial upgrading.

| Variable                 | (1)                | (2)                | (3)                |
|--------------------------|--------------------|--------------------|--------------------|
|                          | Promotion          | GTFP               | GTFP               |
| Time × Treat             | 0.03 ***<br>(3.17) |                    | 0.28 ***<br>(4.83) |
| Promotion                |                    | 0.03 **<br>(2.26)  | 0.02 **<br>(2.15)  |
| Constant                 | 3.14 ***<br>(6.43) | 2.41 ***<br>(4.30) | 2.62 ***<br>(2.92) |
| Individual fixed effects | YES                | YES                | YES                |
| Time fixed effect        | YES                | YES                | YES                |
| Observation numbers      | 556                | 556                | 556                |
| $R^2$                    | 0.72               | 0.63               | 0.75               |

Note: \*\*\*, \*\* are significance levels of 1% and 5%.

## 6. Further Research

The DID method has evaluated the overall effectiveness of green finance subsidy policies, but the policy effects in each province are unknown. SCM can address this limitation. Select 24 provinces that did not implement the interest subsidy policy in 2017 as the control group, and apply the SCM method to conduct a “counterfactual” test on pilot provinces by province (the information on green finance subsidy policies in pilot provinces is shown in Appendix A). Table 9 shows the constituent provinces and their matching weights for the six composite provinces. It can be seen that Hebei is composed of five provinces, with Jiangsu having the highest matching weight; Anhui is composed of three provinces, ranked by weight as Shaanxi, Guangxi, and Henan; Chongqing is composed of four provinces, with Fujian having the highest weight; Beijing is composed of three provinces, with Ningxia having the highest weight; Xinjiang is composed of four provinces, with Sichuan having the highest weight; and Hunan is composed of three constituent provinces, with Hubei having the highest weight.

**Table 9.** Composition provinces and their matching weights of synthesized provinces.

| Synthetic Province     | Composition of Provinces | Weight | Synthetic Province    | Composition of Provinces | Weight |
|------------------------|--------------------------|--------|-----------------------|--------------------------|--------|
| Synthesis of Hebei     | Tianjin                  | 0.098  | Synthesis of Xinjiang | Sichuan                  | 0.162  |
|                        | Zhejiang                 | 0.124  |                       | Hainan                   | 0.208  |
|                        | Guizhou                  | 0.256  |                       | Gansu                    | 0.266  |
|                        | Jiangsu                  | 0.446  |                       | Guangxi                  | 0.364  |
|                        | Fujian                   | 0.076  |                       |                          |        |
| Synthetic Province     | Composition of provinces | Weight | Synthetic Province    | Composition of provinces | Weight |
| Synthesis of Chongqing | Guangdong                | 0.302  | Synthesis of Anhui    | Shaanxi                  | 0.454  |
|                        | Shandong                 | 0.146  |                       | Shanxi                   | 0.28   |
|                        | Fujian                   | 0.449  |                       | Henan                    | 0.266  |
|                        | Jilin                    | 0.103  |                       |                          |        |
| Synthetic Province     | Composition of provinces | Weight | Synthetic Province    | Composition of provinces | Weight |
| Synthesis of Beijing   | Shanxi                   | 0.134  | Synthesis of Hunan    | Jiangxi                  | 0.131  |
|                        | Shaanxi                  | 0.372  |                       | Hubei                    | 0.536  |
|                        | Ningxia                  | 0.494  |                       | Liaoning                 | 0.333  |

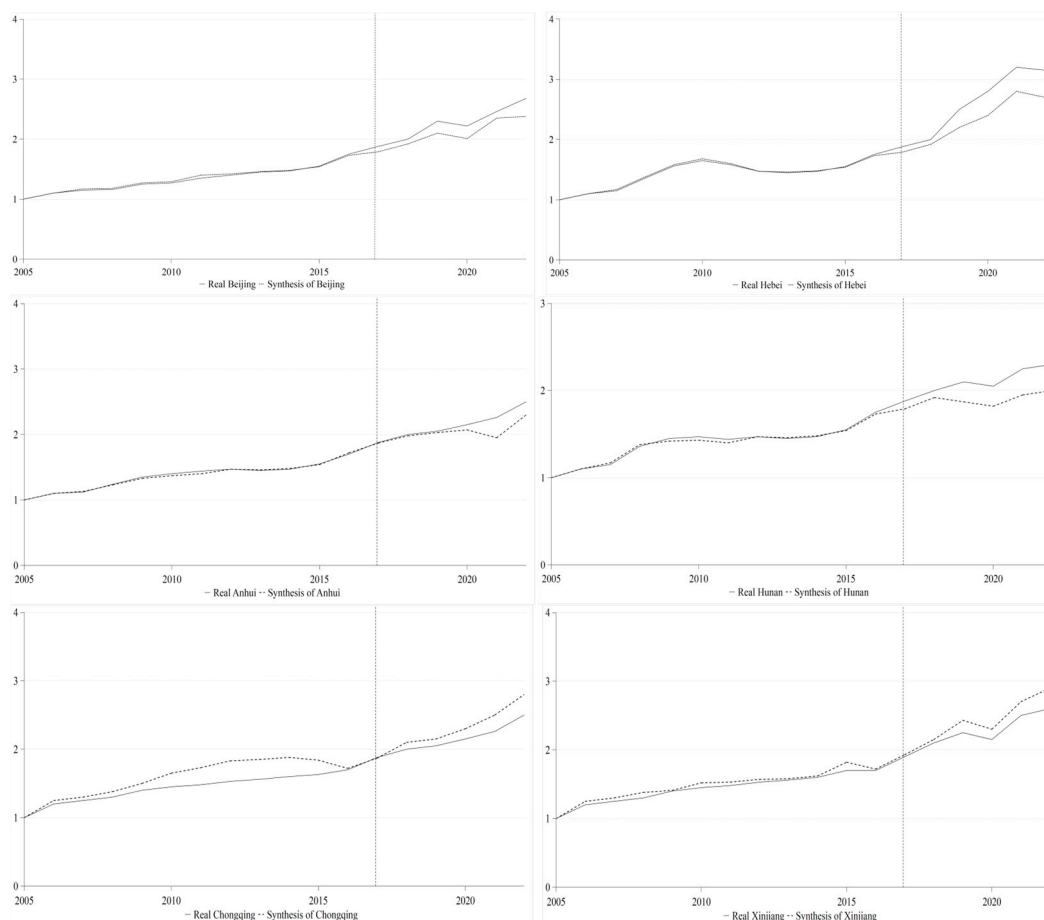
Figure 4 clearly presents the evolution trajectory of GTFP in six pilot provinces and their composite control groups from 2005 to 2022. After the implementation of the policy,

the difference between each real province and its composite control group on this indicator is the policy effect of green finance credit discount. Overall, the direction of change between the real provinces and the synthetic control group is consistent, and the fitting effect is good.

The green finance credit subsidy policies in Hebei, Beijing, and Hunan have achieved significant results. Before 2017, the green total factor productivity levels of real Hebei (Beijing, Hunan) and synthetic Hebei (Beijing, Hunan) were close and consistent in trend. After 2017, the real values of both regions were higher than the composite value, indicating that the real province exceeded its composite control group in this indicator. This confirms that the green finance credit discount policy has a significant promoting effect on the improvement of GTFP in Hebei (Beijing, Hunan).

The policy effect in Anhui Province lags behind by two years. After 2020, its real value began to exceed the composite value, and the green total factor productivity of real Anhui exceeded that of composite Anhui, with the gap continuing to widen.

The green finance policies in Chongqing and Xinjiang have limited effectiveness. After 2017, the real values of the two places were lower than the composite value, indicating that the policy effect was not significant. There are three reasons for this: firstly, the green industry has the characteristics of a long cycle, high cost, and slow effectiveness, with high technological and market uncertainty. The credit subsidy policy is still in its infancy, and its role in improving GTFP has not yet been fully demonstrated; secondly, this policy is essentially a financial policy, and the financial infrastructure and resources in western regions such as Chongqing and Xinjiang are weak and scarce; thirdly, limited by the level of regional macroeconomic development, urbanization and industrial processes are relatively slow, and policy implementation space is restricted.



**Figure 4.** The trajectory of changes in green total factor productivity (GTFP) for each real province and its composite provinces.

## 7. Research Conclusions and Policy Recommendations

This article is based on panel data from 30 provinces (cities, autonomous regions) in China from 2005 to 2022, and constructs indicators to evaluate the GTFP of each province over the years. Using the DID double difference method, mediation effect model, and synthetic control method, this study systematically examines the impact of green credit subsidy policies on green total factor productivity. Research has found that (1) after the implementation of green credit subsidy policies, the GTFP of 30 provinces (cities, autonomous regions) showed an upward trend during the study period. (2) This policy significantly promotes the improvement of green total factor productivity, and this conclusion still holds true under robustness and placebo tests. (3) Intermediary analysis shows that policies mainly enhance green total factor productivity through three key paths: promoting technological innovation, expanding green credit scale, and promoting industrial upgrading, all of which play a significant intermediary role. (4) Through the SCM synthesis control method for regional investigation, the results show that the policy effects of each pilot province are not the same. Beijing, Hebei, and Hunan provinces generally show positive policy effects. Due to differences in resource endowments and other factors in each region, the policy effects of Chongqing and Xinjiang have not been apparent.

Based on the foregoing empirical findings, this study proposes the following institutional optimization framework: (1) Comprehensively expand the coverage of the ecological loan interest compensation system, while reinforcing regional adaptability in the implementation process. Existing evidence has confirmed that this system exerts a significant improvement effect on ecologically integrated output efficiency. It is necessary to systematically review the effective practices and typical cases from pioneering regions, closely integrate local natural conditions, industrial bases, and market characteristics, expand the system's coverage according to local conditions, explore differentiated implementation pathways, and formulate sustainable financing policies aligned with local development stages, thereby effectively steering the economy and society toward a low-carbon transition. (2) Strengthen the institutional coupling among process innovation, green credit allocation, and industrial structural upgrading, and accelerate the transformation of technological achievements into productive forces. This system has effectively enhanced ecologically integrated output efficiency by stimulating innovation activities. Administrative authorities should employ fiscal and tax incentives, R&D subsidies, and other policy instruments to guide business entities to expand investment in clean process R&D and support the growth of the green environmental protection industry. They should also actively build collaborative R&D networks between academia and industry, improve the efficiency of knowledge transfer from the research side to the industrial application side, and accelerate the commercialization of clean technology outcomes. At the same time, the legal protection system for clean technology intellectual property should be strengthened, infringements should be regulated in accordance with the law, and the legitimate interests of innovation entities should be effectively safeguarded. (3) The key priority is to accelerate the construction of sustainable finance infrastructure in the central and western regions, where the basic support for the implementation of financing systems remains significantly inadequate. Efforts should be made to strengthen capacity-building in sustainable finance and long-term development among local administrative authorities, business entities, and the general public, raising their awareness of low-carbon development; to thoroughly explore regional characteristic resource endowments and formulate targeted policy packages to support local clean industry development; and to increase investment in key physical infrastructure such as transportation backbone networks, enhancing their

modernization carrying capacity. At the same time, administrative authorities should actively guide capital supply institutions to develop customized sustainable financing products and service systems that meet the actual needs of the central and western regions.

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## Appendix A

**Table A1.** Green credit subsidy policy.

| Area      | Policy Implementation Time | Policy Name                                                                                                                                        | URL                                                                                                                                                                                                            |
|-----------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hebei     | 7 March 2027               | Notice on Issuing the 13th Five-Year Plan for Ecological Environment Protection in Hebei Province                                                  | <a href="https://hbepb.hebei.gov.cn/hbhjt/zwgk/fdzdgnr/guihua-zongjie/guihua/101633000446767.html">https://hbepb.hebei.gov.cn/hbhjt/zwgk/fdzdgnr/guihua-zongjie/guihua/101633000446767.html</a> (4 March 2026) |
| Anhui     | 23 August 2017             | Opinions of the People's Government of Anhui Province on Promoting Stable and Healthy Economic Development                                         | <a href="https://www.gov.cn/xinwen/2017-04/17/content_5186347.htm#1">https://www.gov.cn/xinwen/2017-04/17/content_5186347.htm#1</a> (4 March 2026)                                                             |
| Chongqing | 7 November 2017            | Chongqing Green Finance Development Plan (2017–2020)                                                                                               | <a href="https://www.docin.com/p-2052724305.html">https://www.docin.com/p-2052724305.html</a> (4 March 2026)                                                                                                   |
| Gansu     | 3 January 2018             | Opinions of the General Office of the People's Government of Gansu Province on Building a Green Financial System                                   | <a href="https://www.docin.com/p-2052724305.html">https://www.docin.com/p-2052724305.html</a> (4 March 2026)                                                                                                   |
| Sichuan   | 18 January 2018            | Notice on Issuing the Development Plan for Green Finance in Sichuan Province                                                                       | <a href="https://www.sc.gov.cn/10462/c103046/2018/1/23/3bb4ad88ea4e47e8abc70f7afde2122e.shtml">https://www.sc.gov.cn/10462/c103046/2018/1/23/3bb4ad88ea4e47e8abc70f7afde2122e.shtml</a> (4 March 2026)         |
| Beijing   | 11 September 2017          | Notice on Issuing the Implementation Measures for Building a Green Financial System in the Capital                                                 | <a href="https://www.beijing.gov.cn/zhengce/zhengcefagui/201905/t20190522_60487.html">https://www.beijing.gov.cn/zhengce/zhengcefagui/201905/t20190522_60487.html</a> (4 March 2026)                           |
| Hunan     | 29 December 2017           | Hunan Province Issues Implementation Opinions to Promote the Development of Green Finance                                                          | <a href="https://lyj.hunan.gov.cn/ztzl/lshn_77586/201712/t20171229_4913612.html">https://lyj.hunan.gov.cn/ztzl/lshn_77586/201712/t20171229_4913612.html</a> (4 March 2026)                                     |
| Xinjiang  | 1 July 2017                | Implementation Opinions on Building a Green Financial System in the Autonomous Region                                                              | <a href="https://www.xinjiang.gov.cn/xinjiang/gfxwj/201707/b2fc3507faa1424788e619a56b342ab.shtml">https://www.xinjiang.gov.cn/xinjiang/gfxwj/201707/b2fc3507faa1424788e619a56b342ab.shtml</a> (4 March 2026)   |
| Fujian    | 29 September 2018          | Implementation Opinions on Strengthening the Linkage between Green Finance and Environmental Credit Evaluation to Promote High-Quality Development | <a href="https://sthj.fujian.gov.cn/xxgk/zfxxgkzl/zfxxgkml/fgwj/201809/t20180929_2148882.htm">https://sthj.fujian.gov.cn/xxgk/zfxxgkzl/zfxxgkml/fgwj/201809/t20180929_2148882.htm</a> (4 March 2026)           |

|         |                  |                                                                                                                          |                                                                                                                                                                                                                                                                      |
|---------|------------------|--------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hainan  | 29 March 2018    | Notice on the Implementation Plan for Green Finance Reform and Development in Hainan Province                            | <a href="https://www.hainan.gov.cn/hainan/szfbgtwj/201804/29b3cc223a7143d888fb155f89b2385c.shtml">https://www.hainan.gov.cn/hainan/szfbgtwj/201804/29b3cc223a7143d888fb155f89b2385c.shtml</a> (4 March 2026)                                                         |
| Guizhou | 24 July 2018     | Guiding Opinions on Promoting Forestry Reform and Development with Green Finance                                         | <a href="https://www.sino-gf.com.cn/3007/">https://www.sino-gf.com.cn/3007/</a> (4 March 2026)                                                                                                                                                                       |
| Guangxi | 25 July 2018     | Implementation Opinions on Building a Green Financial System                                                             | <a href="http://www.gxzf.gov.cn/zfgb/2018nzfgb_35273/d15q_35326/zzqrmzfbgtwj_35327/t1512643.shtml">http://www.gxzf.gov.cn/zfgb/2018nzfgb_35273/d15q_35326/zzqrmzfbgtwj_35327/t1512643.shtml</a> (4 March 2026)                                                       |
| Xizang  | 14 November 2018 | Xizang Autonomous Region's 13th Five-Year Plan for Energy Conservation and Emission Reduction and Implementation Plan    | <a href="https://www.xizang.gov.cn/zwgk/xxfb/ghjh_431/201902/t20190223_61946.html">https://www.xizang.gov.cn/zwgk/xxfb/ghjh_431/201902/t20190223_61946.html</a> (4 March 2026)                                                                                       |
| Jiangsu | 10 October 2018  | Implementation Opinions on Deepening the High-Quality Development of Green Financial Services and Ecological Environment | <a href="https://czt.jiangsu.gov.cn/art/2018/10/10/art_51172_7836535.html">https://czt.jiangsu.gov.cn/art/2018/10/10/art_51172_7836535.html</a> (4 March 2026)                                                                                                       |
| Shanxi  | 11 June 2020     | Management Measures for the Use of Discounted Funds for Clean Development Entrusted Loans by the Financial Department    | <a href="https://www.shanxi.gov.cn/zfxgk/zfxgkzl/zc/xzgfxwj/bmgfxwj1/szfzcbm_76475/sczt_76483/202211/t20221117_7445923.shtml">https://www.shanxi.gov.cn/zfxgk/zfxgkzl/zc/xzgfxwj/bmgfxwj1/szfzcbm_76475/sczt_76483/202211/t20221117_7445923.shtml</a> (4 March 2026) |
| Jilin   | 4 November 2019  | Several Opinions on Promoting the Development of Green Finance                                                           | <a href="https://xxgk.jl.gov.cn/szf/gkml/201911/t20191107_6134293.html">https://xxgk.jl.gov.cn/szf/gkml/201911/t20191107_6134293.html</a> (4 March 2026)                                                                                                             |

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