Green Finance Empowers the Organic Integration of Industries Research on Tool Innovation, Sustainable Development Effects, and Mechanisms of Action

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Abstract: Achieving "carbon peaking" before 2030 and "carbon neutrality" before 2060 is a solemn commitment made by our country to the international community. Vigorously developing green finance to promote the green and low-carbon transformation of our economy is an inevitable requirement for realizing the structural reform of the financial supply side and promoting high-quality development. Under the background of the "dual carbon" strategy, green finance is regarded as a key institutional arrangement driving the green transformation of industries. This paper, by integrating interdisciplinary perspectives from environmental economics, corporate finance, and institutional economics, constructs a three-dimensional analysis of "financial instruments-industry characteristics-institutional environment," systematically exploring the mechanism and sustainable development effects of green financial instrument innovation on industrial green transformation. Based on a comparative analysis of green credit, green bonds, green insurance, and derivative instruments, it is found that green finance effectively guides capital flow from high-carbon assets to green industries through mechanisms such as differentiated financing costs, risk mitigation, and performance incentives, significantly enhancing corporate environmental performance and total factor productivity. Furthermore, it reveals that green finance promotes industrial structure optimization and systemic carbon emission reduction at the macro level by optimizing resource allocation, reducing financing costs, and strengthening environmental constraints. At the micro level, it reshapes the investment decision boundaries of enterprises, fostering the research, development, and diffusion of green technologies. The research findings provide a theoretical basis for the government to formulate precise green finance methods, offer practical guidance for enterprises to implement green transformation strategies, and supply interdisciplinary theoretical support for building a green finance system that balances efficiency and inclusivity.

Keywords: Green Finance; Organic Integration of Industries; Industrial Transformation; Tool Innovation; Sustainable Development Effect

1. Research Background and Objectives

1.1 The Development Trends of Global Green Finance

Globally, the expansion of green finance has been remarkably rapid, becoming a critical driver in addressing climate issues and promoting sustainable development. With the gradual implementation of international environmental agreements such as the Paris Agreement, governments and financial institutions across countries are collaborating

[1], leveraging policy guidance and market mechanisms to jointly advance the construction of the green finance system. From a global perspective, green finance has evolved from an initial environmental concept into a comprehensive system encompassing various tools and multi-tiered markets. Its primary mission is to direct capital towards low-carbon and environmentally friendly industries, achieving a win-win scenario of economic development and environmental protection. On September 22, 2020, General Secretary solemnly declared at the general debate of the 75th session of the United Nations General Assembly that China would strive to peak carbon dioxide emissions by 2030 and make every effort to achieve carbon neutrality by 2060. Subsequently, the relevant central authorities established the "1+N" policy system for carbon peaking and carbon neutrality, guiding government departments at all levels, enterprises, and other relevant market entities to implement the "dual carbon" strategy [2]. The establishment of the "Dual Carbon" goals has set specific requirements for enterprises in terms of green project identification, climate risk management, carbon accounting, carbon information disclosure, and ESG information disclosure. Small and medium-sized enterprises (SMEs), which account for more than 99% of the total number of enterprises in the country, are not only the key players in driving the achievement of carbon peak and carbon neutrality, but also a powerful force in promoting innovation, fostering employment, and improving people's livelihoods.

From the perspective of driving factors, the rise of green finance is primarily driven by three aspects. Firstly, there has been a widespread increase in environmental risk awareness, with financial institutions paying more attention to climate-related financial disclosures. Secondly, policy incentives have been continuously improved, covering the application of tools such as tax incentives and risk compensation. Thirdly, investor preferences have shifted, with the widespread adoption of ESG investment concepts prompting capital to actively allocate to green assets. The integration of digital technology and green finance is fostering new service models. Innovative practices such as the application of blockchain technology in carbon asset tracking and the use of artificial intelligence for environmental risk assessment are enhancing the efficiency and transparency of capital allocation. However, the current development still faces the issue of regional imbalance. Developed countries, leveraging their first-mover advantage, have established relatively comprehensive green finance infrastructures, while developing countries exhibit significant gaps in areas such as standard setting and capacity building. In the future, global green finance will exhibit three major trends: first, cross-border cooperation will be strengthened, promoting international capital flows through common classification standards [3]; second, tool innovation will be deepened, with new products such as climate derivatives and natural bonds enriching market choices [4]; and third, industrial synergy will be reinforced.

1.2 The Current State of Organic Integration in the Industry

The process of industrial green transformation is accelerating globally. However, the integration of traditional industries with green finance is still constrained by various structural contradictions. High-energy-consuming and high-emission industries are experiencing slow progress in their transformation due to characteristics such as locked technical pathways, asset specificity, and long-cycle returns. There is a significant mismatch between the financing needs of these industries and green finance's preference for short-term returns. Although leading companies in industries like steel and cement have raised the necessary funds for low-carbon technological upgrades through tools like green bonds, a large number of small and medium-sized enterprises are struggling to obtain effective financial support due to insufficient collateral and incomplete environmental information disclosure. Strategic emerging industries such as new energy, energy conservation, and environmental protection, despite their green attributes, face cautious lending from financial institutions due to lower technological maturity and less stable business models [5]. In terms of industrial synergy, the integration of cross-sectoral green value chains has not yet achieved economies of scale. Green financial resources are excessively concentrated in the end-product stage, with insufficient support for the greening transformation of upstream supply chains. The recycling and echelon utilization of new energy vehicle batteries face challenges due to the lack of

technical standards and poor economic viability, making it difficult to attract large-scale investment, thereby limiting the green synergy effect across the entire industrial chain. At the regional level, the eastern coastal areas have established a relatively comprehensive green industry ecosystem by leveraging the first-mover advantage of policies. In contrast, the central and western regions face developmental bottlenecks due to a lack of green project reserves and a shortage of professional service institutions. The inconsistency in evaluation systems exacerbates these contradictions. The current green industry directory does not clearly define projects for the transformation and upgrading of traditional industries, making it difficult for financial institutions to accurately quantify environmental benefits. The absence of a risk-sharing mechanism creates a conflict between the high failure rate in the initial stages of green technology application and the risk preferences of financial institutions. There is a lack of effective guarantee, insurance, and reinsurance tools for risk mitigation. Data barriers result in the dispersion of corporate carbon footprints and environmental performance information across multiple departments such as environmental protection, taxation, and energy regulation, leading to high costs for financial institutions to obtain and verify this information, thereby limiting the efficiency of green credit approval [6]. The aforementioned systemic barriers collectively result in a "green financing gap" on both the supply and demand sides of capital, where there is a strong demand for financing in environmental projects but a low actual funding fulfillment rate. Since 2025, the implementation of international regulations such as the Carbon Border Adjustment Mechanism has imposed external constraints on export-oriented industries, accelerating their green transformation. This has also created new opportunities for the deep integration of green finance and industries, while raising higher requirements for cross-border green certification, carbon accounting, and information disclosure. In the future, there is an urgent need to rely on innovative mechanisms such as the establishment of industrial green transformation funds, the development of structured financial products linked to carbon emission rights, and the construction of blockchain-based environmental data sharing platforms, to achieve a leap from single-point support to systematic empowerment [7].

Although the academic community has accumulated a substantial body of research on the economic effects of green finance and its driving factors, the exploration of the intrinsic mechanisms and enabling pathways of its institutional openness remains in the preliminary stages, lacking a systematic theoretical framework. A thorough analysis of the core essence of institutional openness in green finance, a comprehensive explanation of its essential characteristics, and a systematic organization of its enabling mechanisms will not only enrich the theoretical system of green finance and provide a more robust theoretical basis for related practices; from the perspective of practical application, this research will also point the way for high-quality economic development, offer scientific policy references for decision-makers, assist financial institutions in optimizing their business layouts, and promote the healthy and orderly development of the green finance market.

1.3 Research Significance

This study aims to systematically explore the inherent laws and practical pathways of the organic integration between green finance and industry. At the micro level, the study places various financial instruments such as green credit, green bonds, sustainability-linked loans, transition bonds, and carbon asset pledge financing within a unified analytical framework. It dissects their pricing logic, risk mitigation clauses, and performance trigger conditions, illustrating how these financial tools reshape corporate investment boundaries across dimensions such as capital cost, term structure, risk sharing, and signal transmission. This aims to optimize the intertemporal and cross-industry allocation of funds, reduce environmental risk premiums, thereby driving low-carbon upgrades in traditional industries and facilitating the scale expansion of emerging industries. To this end, a multi-dimensional compatibility evaluation framework is constructed, incorporating industrial technology characteristics, asset specificity, cash flow structure, and financial instrument attributes. This framework identifies the differentiated needs of various industries in terms of financing scale, term, risk sharing, and information disclosure, laying the theoretical and quantitative foundation for the precise

matching of financial supply [8]. At the macro level, it transcends the existing research's singular focus on environmental benefits and short-term perspectives, constructing a multi-dimensional dynamic evaluation system that simultaneously encompasses corporate energy conservation and emission reduction, synergistic carbon reduction across the industrial chain, enhancement of regional green competitiveness, and improvement of social welfare. It deliberately introduces the exogenous institutional shock brought about by the comprehensive implementation of the Carbon Border Adjustment Mechanism in 2025, quantitatively analyzing the mechanisms through which green finance reduces the embodied carbon intensity of export-oriented enterprises, alleviates carbon tariff costs, promotes the diffusion of green technologies, and facilitates value chain restructuring, thereby revealing the conditions and pathways for the co-evolution of environmental performance and economic benefits. At the mechanism optimization level, addressing the systemic barriers of the green gap at the industrial end, it proposes a comprehensive solution encompassing policy, market, and technology dimensions, At the policy level, construct a policy tool combination including dynamic adjustment of the green industry catalog, mandatory environmental information disclosure standards, fiscal interest subsidies and risk compensation funds, government financing guarantees and reinsurance, and evaluate their synergistic effects and marginal benefits. At the market level, consider how ESG investment concepts reshape industrial financing constraints through capital cost differentials, shareholder activism, and reputational constraints, while analyzing the incentive effects of new capital structures such as green funds, carbon-neutral bond index funds, and blended finance. At the technological level, demonstrate the enabling mechanisms of digital technologies such as blockchain traceability, IoT real-time monitoring, big data risk control, and AI environmental performance assessment in reducing information asymmetry, enhancing the operational efficiency of green finance, and expanding service boundaries. Ultimately, provide interdisciplinary theoretical support and actionable policy recommendations for building a financial support system for industrial green transformation that balances efficiency and inclusivity [9].

2. The Theoretical Foundation of Green Finance

The theoretical foundation of green finance is deeply rooted in the integration of multiple disciplines such as environmental economics, corporate finance, public economics, and institutional economics. It continues to evolve and develop within the progress of sustainability theory, climate finance theory, financial function theory, and financial ecology theory. The core of green finance lies in explaining how financial capital, through mechanisms of pricing, risk management, and resource allocation, transforms environmental externalities into internalities, thereby driving the real economy towards a low-carbon, circular, and resilient transformation. The theory of sustainable development lays the value-theoretical foundation for green finance, integrating the three major systems of economy, society, and environment into a unified analytical framework. It mandates that the stock of natural capital should not decrease, based on the principles of intergenerational equity and strong sustainability. In this context, finance transcends the realm of profit maximization, transforming environmental constraints into investment opportunities through institutional innovation, thereby achieving three-dimensional Pareto improvement. Climate finance theory builds upon the foundation of sustainable development theory by introducing the social cost of carbon, categorizing climate risks into physical risks and transition risks, and employing carbon pricing [10], scenario analysis, and stress testing [11] to convert future emission constraints into current asset premiums or impairments, thereby driving capital from high-carbon assets to low-carbon assets. The internalization of environmental externalities, guided by Pigouvian taxes and the Coase theorem, reveals the root causes of market failures [12]. Green credit spreads, green bond premiums, carbon asset collateralization, and sustainability-linked clauses transform greenhouse gas and pollutant emissions into corporate financial costs or benefits, steering microeconomic entities to autonomously adjust their investment and technological pathways. Government subsidies, interest subsidies, and risk compensation funds aim to bridge the gap in public goods supply by reducing transaction costs and risk premiums. Under the

Merton-Bodie framework, financial function theory emphasizes the information processing, risk management, and incentive compatibility functions of green finance, relying on environmental information disclosure, ESG ratings, and blockchain traceability to mitigate information asymmetry. Utilize green insurance, guarantees, and climate derivatives to diversify environmental technology and policy risks, and achieve reverse linkage between environmental performance and financing costs through KPI/SPT performance clauses. Financial ecology theory and institutional economics illustrate that the operation of green finance relies on a multi-level governance structure composed of laws, regulations, and social norms. At the macro level, it is necessary to unify information disclosure standards, green classification catalogs, and international mutual recognition mechanisms. At the macro level, exchanges, rating agencies, third-party certifications, and digital infrastructure need to collaborate. At the micro level, financial institutions must integrate environmental risks into their comprehensive risk management systems and achieve long-term value creation through board-level ESG governance. The evolution of institutions has path-dependent characteristics, and early policy signals, demonstration projects, and standard competition jointly determine the future equilibrium form. The user's input is in Chinese and it needs to be translated into English. Please ensure the translation is accurate and meets the requirements.

2.1 The Main Instruments of Green Finance

Green financial instruments have gradually evolved into a diversified vehicle encompassing debt, equity, and derivative instruments [13], playing two critical roles in the green transformation of industries: resource allocation and risk governance. In the realm of debt, green credit and green bonds serve as the primary tools. Green credit links financing costs directly to a company's energy efficiency and emission performance through differentiated interest rates and credit quota management, providing debt financing with flexible terms and affordable costs for low-carbon technological upgrades in capital-intensive industries. Green bonds, on the other hand, utilize mechanisms such as earmarked funds, third-party certification, and continuous information disclosure to ensure the direction of raised capital. Their renewable structures can align with the longer payback periods of renewable energy projects, thereby reducing refinancing risks. In terms of equity, it includes green industry funds and ESG-themed investments. Green industry funds mostly adopt a model where the government and social capital jointly bear the risks, focusing on investing in areas with high technological barriers and high growth potential such as hydrogen energy, energy storage, and carbon capture, thereby addressing early market failures. ESG-themed investments, based on secondary market screening mechanisms, integrate environmental performance with capital premiums, encouraging companies to continuously improve the depth of information disclosure and carbon management capabilities. In the derivatives sector, there are carbon quota pledge loans [14], emissions trading [15], energy use rights futures, and climate derivatives [16]. By transforming carbon assets and environmental rights into financial instruments that can be pledged, traded, and hedged, a real-time price signal for emission reduction benefits and pollution costs is established. Additionally, with blockchain traceability and smart contract technology, automatic triggering of environmental performance and financing conditions, along with immutable records, are achieved, reducing transaction costs and operational risks. By leveraging the complementary functionalities of these three types of tools in the industrial sector, debt instruments drive the green transformation of traditional production capacities through low-cost leverage, equity instruments foster emerging green technologies via risk-sharing, and derivative instruments incentivize emission reductions across the industrial chain through price discovery and hedging. Together, they form a comprehensive green financial services network that covers the entire lifecycle of enterprises and spans the upstream and downstream sectors. With the full implementation of the Carbon Border Adjustment Mechanism by 2025, cross-border green financial products linked to carbon emission intensity are expected to become a new frontier of innovation, enhancing the financial sector's role in empowering the global industrial transition to low-carbon practices. As shown in Figure 1.

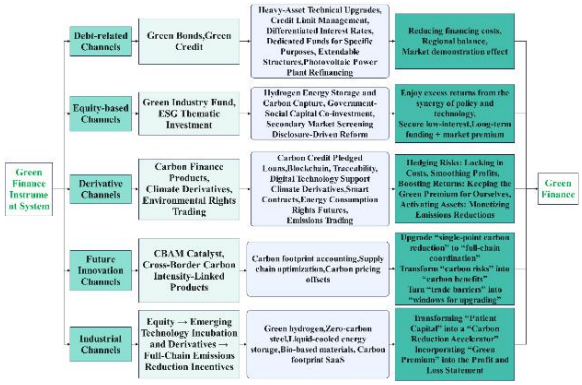

Figure 1. Mechanism Diagram of Green Finance Empowering the Organic Integration of Industries

2.2 The Current Development Status of the Organic Integration Industry

Globally, the organic integration industry is entering a period of accelerated expansion, with its evolutionary characteristics summarized in terms of three elements: scale, space, and technology. From the perspective of scale, the combination of carbon neutrality commitments and innovations in green financial instruments has led to a continuous increase in investment in sectors such as renewable energy, energy storage, and energy-saving services. Within the funds raised through green bonds, the proportion allocated to wind power and photovoltaic projects has been increasing year by year, creating a positive feedback loop between capital and technology. In terms of spatial dimensions, the industry exhibits a highly clustered pattern. Developed countries rely on mature capital markets and institutional environments to establish green technology industrial parks, achieving integration of research and development, manufacturing, and services. Developing countries leverage their resource endowments and cost advantages to build specialized bases around characteristic resources. For example, the Yangtze River Delta integrates new energy vehicles as a core to consolidate battery recycling and charging networks, while the Pearl River Delta focuses on green home appliances and energy-efficient electronics, achieving carbon reduction across the entire chain through green supply chain management. Within these clusters, infrastructure and information flows are shared, effectively reducing transaction costs and accelerating technology diffusion. From a technical perspective, the annual growth rate of green and low-carbon patents has exceeded double digits, with groundbreaking applications emerging in agriculture, industry, and the service sector. Innovations such as real-time optimization of energy consumption through the Internet of Things, full traceability of product carbon footprints via blockchain, and process advancements like hydrogen-based steelmaking and bio-based material substitution collectively form a cross-industry technological matrix. At the industrial structure level, heavy industries are reducing emissions through upgrades in processes and equipment, while consumer goods manufacturing is shifting towards green materials and reduced packaging. In the service sector, new business models like green finance and carbon asset management provide consulting, risk control, and funding channels for the transition [17-19]. After the full implementation of the Carbon Border Adjustment Mechanism in 2025, export-oriented industries accelerated low-carbon certification and technological iteration to avoid carbon tariffs, amplifying the coupling effect between green finance and the real economy. On the policy front, governments around the world utilized tools such as green procurement, tax reductions, and interest-subsidized guarantees to lower the marginal costs of green investments. Financial institutions continued to introduce loans, bonds, insurance, and derivatives linked to carbon intensity and environmental performance, creating an institutional environment where policy incentives and market mechanisms synergistically function. This drives industries to shift from passive compliance to endogenous innovation, indicating that organically integrated industries will play a lasting engine role in the restructuring of the global value chain and high-quality economic growth.

3. Innovation in Green Financial Instruments

3.1 Types and Characteristics of Green Financial Instruments

3.1.1 Green credit

Green credit, as a fundamental debt instrument within the green financial system, internalizes environmental externalities into bank credit decisions through three mechanisms: differentiated interest rates, credit lines, and term structures, thereby guiding the allocation of funds. At the product level, green credit exclusively targets environmentally friendly

sectors such as energy conservation, clean energy, and the circular economy. Its interest rates are generally 10%-30% below the benchmark and are subject to environmental benefit assessments conducted by independent third parties. These assessments evaluate project boundaries, baseline scenarios, emission reduction calculations, and monitoring plans to ensure the exclusivity and verifiability of fund usage. At the implementation level, the bank has established a dual screening model of "finance+environment." On one hand, it continues to employ traditional methods such as cash flow, asset-liability, and guarantee assessments. On the other hand, it incorporates the environmental credit ratings of enterprises from environmental protection departments, the carbon emissions over the project lifecycle, and pollution emission indicators. For green entities, it increases credit limits, extends loan terms, and simplifies approval processes. For industries with high pollution, high energy consumption, and overcapacity, it implements a list-based compression or exit strategy, integrating both credit risk and climate transition risk into the risk control system. Its application scenarios involve clean production transformation in heavy-asset industries, renewable energy infrastructure construction, and resource recycling facility development. After the expansion of the national carbon market in 2025, a series of banks introduced floating-rate loans linked to carbon emission reduction performance, with the interest rate fluctuation range dynamically connected to the completion of certified emission reductions, creating market-driven incentives. Leveraging the extensive branch networks and highly digitalized approval processes of banks, green credit achieves inclusive coverage for both large enterprises and SMEs. Empowered by the digital economy, the approval cycle has been shortened from 2-3 months to within two weeks, reducing financing time costs. However, its risk appetite remains relatively conservative, with insufficient support for early-stage high-growth, high-uncertainty green technology R&D. There is a need for collaborative efforts with green industry funds, green bonds, and carbon asset pledges to build a diversified financing system that covers the entire project lifecycle.

3.1.2 Green bond

Green bonds are a debt financing instrument specifically designed to raise funds for environmentally friendly projects. Their essential characteristic is the tight linkage between the use of raised funds and verifiable environmental benefits, achieved through legal frameworks and third-party certification mechanisms. This ensures that the funds are directed towards green sectors such as renewable energy, pollution control, energy efficiency, and the circular economy. Compared to traditional bonds, green bonds exhibit advantages in three aspects: information disclosure, investor structure, and policy incentives. The issuer is required to regularly disclose independently verified environmental benefit reports, ensuring a high level of transparency in the flow of funds. Long-term capital such as social security funds, pension funds, sovereign wealth funds, and ESG investment funds actively participate due to the demand for responsible investment, thereby diversifying the investor structure. Governments in various regions provide support through explicit policies such as fiscal interest subsidies, income tax reductions, and special relending, which lower financing costs and enhance market liquidity. From the perspective of product structure, green bonds have been refined into four categories: ordinary green bonds, green asset-backed securities (ABS), transition bonds, and carbon-neutral bonds. Ordinary green bonds take pre-qualified green projects as investment targets, while green ABS use the income rights of renewable energy projects and green lease receivables as underlying assets, achieving the revitalization of green assets and risk diversification. Transition bonds provide special funds for low-carbon technology transformation and business model upgrades in high-carbon industries [20]. Carbon neutrality bonds require projects to have quantifiable emission reduction effects and mandate full disclosure of carbon footprint changes, covering the financing spectrum across different industrial stages and emission reduction needs. In terms of operational mechanisms, green bonds have established a "certification-custody-disclosure" tripartite guarantee system. Prior to issuance, qualified assessment agencies conduct green ratings based on the "Green Bond Supported Projects Catalogue" and provide second opinions. During the tenure period, the funds shall be managed in a closed and dedicated account, with the introduction of blockchain smart contracts to track the fund flow in

real-time, mitigating the risk of misappropriation. Upon maturity, a specialized environmental performance report that has been independently verified must be published, disclosing the proportion of funds invested, the amount of energy saved and emissions reduced, as well as social benefit indicators, before the funds can be released into the market. The role of green bonds in promoting industrial upgrading is reflected in the dual effects of term matching and technology spillover. Their duration of five to ten years aligns closely with the long investment recovery cycles of infrastructure such as photovoltaic power stations, offshore wind farms, energy storage systems, and urban solid waste treatment, effectively avoiding the term mismatch of short-term loans for long-term investments. To meet green certification standards, issuers often proactively introduce internationally advanced environmental technologies, management systems, and third-party audits, which facilitate the diffusion and localized application of key technologies such as photovoltaic module recycling, carbon capture, utilization, and storage, and hydrogen production. However, the high credit rating threshold, information disclosure costs, and legal compliance requirements of green bonds pose practical constraints for small and medium-sized enterprises (SMEs). In the future, structured innovations such as government credit enhancement, collective bond issuance, green asset-backed securities, and green bills for SMEs will be needed to broaden financing channels, thereby maintaining a balance between market expansion and inclusive growth [21].

3.1.3 Green insurance

Green insurance, as a risk transfer financial tool [22], incorporates environmental risks into actuarial models through market mechanisms and explicitly prices them in insurance contracts. This approach provides a closed-loop safeguard for the green transformation of industries, offering preventive measures beforehand, compensatory actions during, and improvements after the event. Its product spectrum has now differentiated into three major categories: environmental pollution liability insurance, green project performance insurance, and climate-related insurance. Environmental pollution liability insurance is responsible for covering the liability of enterprises for personal and property damages caused to third parties due to sudden accidents. Green project performance insurance provides guarantees for completion risks and power generation shortfall risks that may occur during the construction and operation phases of renewable energy projects. Climate-related insurance offers economic compensation for physical losses caused to green infrastructure by extreme events such as typhoons, floods, and droughts. Compared to traditional capital supply tools such as credit and bonds, the core feature of green insurance lies in its proactive risk management and the environmentally binding conditions for triggering claims. Specifically, policyholders are required to continuously meet certain emission standards and implement risk rectification measures before they can receive claims. This mechanism is predicated on the mutual coupling of external supervision and internal incentives. Green insurance has prompted enterprises to enhance their environmental management systems. Operationally, it has established a comprehensive closed-loop system of 'prevention- compensation-improvement.' Prior to underwriting, insurance companies, in collaboration with environmental protection agencies, utilize remote sensing, drones, and big data analytics to conduct environmental risk assessments and hazard classification for enterprises, subsequently proposing rectification plans. Following an incident, they leverage fast claims settlement channels to mitigate environmental losses and social costs. Throughout the policy period, measures such as floating premiums, no-claim discounts, and reinsurance spreads inversely link the environmental performance of enterprises with insurance rates, thereby encouraging policyholders to continuously invest in pollution control and low-carbon transformation. At the product innovation level, carbon sink insurance employs satellite remote sensing and lidar technology to quantify the carbon sink stock of forests and compensate for the loss of carbon storage precipitated by natural disasters, thus directly supporting the realization of the value of ecological assets. Additionally, green technology insurance offers multiple risk protections against test failures, performance non-compliance, and commercialization delays for cutting-edge technologies, including photovoltaic module recycling, carbon capture, storage, and utilization, as well as hydrogen

energy equipment, thereby reducing the uncertainty associated with enterprise research and development. The premiums for both types of insurance are dynamically linked to the enterprise environmental credit rating, with companies exhibiting high environmental integrity eligible for a premium discount of up to forty percent. The risk-bearing function of green insurance effectively mitigates the risk aversion of banks and the bond market towards high-risk green projects. In the case of offshore wind power projects, an insurance-plus-credit structure is adopted, where insurance companies first underwrite typhoon risks, followed by banks providing construction loans, thereby achieving risk stratification and term matching [23]. According to the currently available data, the incidence of environmental accidents in pilot regions is over 30% lower among insured enterprises compared to uninsured ones, demonstrating a significant preventive effect. However, due to limited affordability of premiums and a lack of historical risk data, the participation rate among small and medium-sized enterprises remains low. To enhance inclusiveness, it is necessary to rely on fiscal subsidies, tax incentives, reinsurance support, or industry co-insurance models. Looking ahead, green insurance is transitioning from single-risk protection to diversified risk management and asset appreciation services. Leading companies have already integrated power generation efficiency guarantees and intelligent operation and maintenance solutions into photovoltaic power station insurance, utilizing IoT technology for real-time monitoring and preventive maintenance to improve asset operation efficiency. In the face of increasingly severe climate change and biodiversity conservation needs, innovative products such as catastrophe bond insurance, climate parameter insurance, and ecological insurance will rapidly advance, continuously expanding the green financial tool system and enhancing its capacity to withstand systemic risks during the green transition.

3.2 Innovative Pathways for Green Financial Instruments

3.2.1 Tool innovation driven by technological innovation

Technological innovation constitutes the endogenous driving force behind the evolution of green financial instruments, while the deep integration of digital technologies and financial products is reshaping the precise matching, risk identification, and operational efficiency of green finance. Blockchain enables real-time on-chain synchronization of green bond fund flows, project progress, and environmental benefits through an immutable distributed ledger, and leverages smart contracts to automatically trigger interest rate step-ups or early redemption clauses when emission reduction targets are not met, thereby transforming environmental commitments into enforceable financial constraints [24]; Big data analytics transcends traditional financial dimensions by incorporating multidimensional environmental data such as corporate energy consumption, emission factors, water usage intensity, and environmental penalty records into green credit scorecards, allowing commercial banks to establish dynamic monitoring and early warning systems that automatically adjust credit conditions upon detection of excessive emissions or violations, achieving a paradigm shift from static due diligence to dynamic management [25]; Artificial intelligence, leveraging machine learning, conducts in-depth training on historical climate disasters, equipment failures, and operational fluctuations, providing precise pricing and rapid claims settlement for new products such as climate index insurance and power generation guarantee insurance. The real-time coupling of satellite remote sensing and meteorological forecasting offers immediate risk barriers for new infrastructures like distributed photovoltaic and decentralized wind power, enabling instant compensation upon contact [26]. The further penetration of fintech has spurred the emergence of inclusive green services, where mobile payments, digital identity authentication, and electronic contract technologies lower the participation threshold for small and medium-sized enterprises. Platform-based supply chain finance splits and circulates the green credit of core enterprises in the form of digital certificates to upstream and downstream small and micro entities, simultaneously transmitting green technology standards and emission reduction requirements in chain financing. In the future, the Internet of Things will further integrate with digital twins to interconnect production equipment, emission monitoring, and financial systems in real time. Dynamic green credit based on continuous

energy consumption and emission data can automatically lower interest rates when emission reduction progress exceeds expectations, while instant sensor feedback on environmental performance can directly trigger insurance premium discounts or the release of reinsurance quotas, forming a closed-loop synergy between industrial green transformation and financial support, continuously amplifying the leverage effect of green finance on sustainable development. The company's core competitiveness lies in its ability to continuously innovate and adapt to market changes.

3.2.2 Tool innovation under policy support

In recent years, governments around the world have established multi-level policy frameworks, including standard setting, fiscal incentives, information disclosure, capacity building, and regional pilots, driving the evolution of green financial instruments from single products to comprehensive solutions. At the macro level, unified and dynamically adjusted technical standards and project catalogs have delineated clear boundaries for the market, enabling financial institutions to accurately identify eligible targets and reduce search and evaluation costs. Differentiated measures such as interest subsidies, targeted reserve requirement ratio cuts, risk compensation funds, and tax incentives, by lowering marginal financing costs and risk premiums, directly enhance the intrinsic motivation of financial institutions to develop new instruments such as green credit, green bonds, transition bonds, and carbon asset pledges. From the perspective of social development, mandatory environmental information disclosure and sustainable finance disclosure regulations compel financial institutions to incorporate environmental externalities into their pricing models, thereby catalyzing the emergence of green assessment, data verification, and scenario analysis tools. The government leverages training, standard-setting, and the construction of third-party certification systems to address the deficiencies of small and medium-sized institutions in green product design, risk measurement, and customer service. For small and medium-sized enterprises, the green finance reform and innovation pilot zones provide a sandbox environment, allowing tools such as carbon reduction-linked loans, environmental rights pledge financing, and green supply chain bills to be tested on a trial basis under controlled risks. Their successful experiences, through fault-tolerant and error-correcting mechanisms, are elevated to national institutional arrangements and integrated into local ecological civilization assessment indicators, thereby reinforcing the rigid constraints of policy implementation. Cross-departmental collaboration has also become a notable trend. Environmental protection, financial regulation, and fiscal departments are leveraging information-sharing platforms to integrate real-time data on pollution discharge permits, energy consumption monitoring, and carbon emission verification into credit approval, re-lending, and interest subsidy processes. This has alleviated information asymmetry and improved approval efficiency. Policy design will revolve around three main lines. Firstly, strengthen the close integration of green financial instruments with the transformation policies of traditional industries such as steel, building materials, and chemicals, and develop transition financial products that are compatible with medium-term emission reduction pathways. Secondly, improve the transition financial framework to provide full lifecycle financial support for technological iterations and process reengineering. Thirdly, promote international alignment of standards through mechanisms such as the Green Investment Principles for the Belt and Road and the Common Ground Taxonomy, and enhance the precision and cross-border applicability of policy implementation by leveraging digital technologies such as blockchain, the Internet of Things, and big data, thereby forming a dynamic synergy of policy incentives, market mechanisms, and technological innovation, and continuously amplifying the leverage effect of green finance on global sustainable transformation [27].

4. The Sustainable Development Impact of Green Finance

4.1 Economic Effect

4.1.1 "Transfuse" the green industry, "cut off" the high-carbon industry

Green finance systematically optimizes the industrial structure through three mechanisms: capital guidance, technological upgrading, and industrial ecosystem reshaping. In terms of capital guidance, tools such as differentiated

interest rates, interest subsidies, and green ratings channel low-cost capital into areas like clean energy and energy conservation, leading to a significant increase in the marginal financing costs for high-pollution and high-energy-consuming industries. This prompts the flow of production factors across different sectors, reshaping investment return expectations. Once the financing costs for enterprises are reduced, it accelerates the clearance of outdated capacity by social capital. At the level of technological upgrading, green bonds, sustainability-linked loans, and green industry funds provide stable and duration-matched funding sources for clean technology R&D and process transformation. Enterprises within high-tech industrial clusters allocate over 30% of their raised capital to green innovation, creating a virtuous cycle of financing, R&D, and large-scale application. Moreover, by leveraging technology spillovers along the industrial chain, they drive a collective reduction in emission intensity across upstream and downstream sectors. In the reshaping of the industrial ecosystem, green finance has established an incentive and constraint system centered on environmental performance. Traditional industries, compelled by financing conditions, have reduced the proportion of high-carbon operations while relying on digital technologies to achieve reduction in quantity, improvement in quality, and enhancement in energy efficiency. Regional disparities are manifested as the western region relies on policy-oriented financial guidance, while the eastern region leans on market self-regulation. Green finance also leverages the synergy between venture capital and green insurance to reduce the uncertainty in technology commercialization, fostering the emergence of new energy-saving and environmentally friendly business models. This has led to a continuous increase in the industry's added value as a proportion of the Gross Domestic Product (GDP). Moreover, once the penetration rate crosses a threshold, it triggers a qualitative transformation in the industrial structure from end-of-pipe treatment to source control.

4.1.2 Support the research and development of green technologies, and strengthen the ecosystem of green industries

In terms of operational efficiency, green credit, green bonds, and sustainable development-linked loans, through interest subsidies, interest rate reductions, and risk compensation mechanisms, have compressed the weighted average financing costs of enterprises. The characteristic of dedicated funds for specific purposes has prompted enterprises to simultaneously carry out energy-saving technological renovations and process optimizations, leading to a decrease in energy consumption per unit of product and an increase in capacity utilization. Form a dual benefit of "cost reduction and efficiency improvement". In terms of market competitiveness, the ESG investment concept and regulatory requirements such as carbon tariffs overlap, making green certification a necessary threshold for entering high-end markets and the global supply chain. Enterprises supported by green finance have a 40% higher R&D intensity than the industry average, and their differentiated low-carbon products and services can achieve a price premium of more than 20% in the international market. And it has increased the share of overseas orders. In terms of social image, the mandatory information disclosure and third-party certification mechanism for green bonds have enhanced corporate transparency, strengthened sustainable brand value, and simultaneously increased consumer trust and positive media coverage. The capital market also offers green enterprises a 15% to 30% price-earnings premium. Moreover, state-owned enterprises and large private enterprises benefit more significantly from policy resources and integration capabilities. The coordinated operation of business performance, market competitiveness and social image has enabled the savings in capital costs, alleviated financing constraints and released space for R&D investment. The market expansion effect, through green certification, has opened up new demands and magnified the premium space. The higher the effectiveness of regional governance, the more coordinated the policy incentives and market mechanisms are, and the more obvious the marginal improvement of enterprise performance brought by green finance, thus forming a virtuous cycle.

4.2 Environmental Effect

4.2.1 The inhibitory effect on carbon emissions.

The inhibitory effect of green finance on carbon emissions can be incorporated into three complementary pathways: capital constraints,

technological incentives, and governance enhancement, which generate progressive effects at multiple levels including macro, industry, and enterprise. In terms of capital constraints, green credit, green bonds, and sustainability-linked loans increase the marginal financing cost of high-carbon assets and limit their refinancing space through mechanisms such as interest rate gradients, term compression, and quota restrictions, while also shortening the duration of these assets. This compels enterprises to adopt measures such as early retirement, process substitution, or capacity replacement to reduce fossil energy consumption. Empirical evidence shows that for every 1 percentage point increase in the proportion of green credit, the carbon emissions per unit output of high-energy-consuming industries decrease by 0.6% to 1.2%, and this elasticity is significantly amplified in regions with higher carbon pricing levels. In terms of technological incentives, mechanisms such as interest subsidies, risk compensation, carbon revenue pledges, green industry funds, and ESG investments have lowered the capital threshold and uncertainty for the research, development, and application of low-carbon technologies. These mechanisms have facilitated the large-scale diffusion of technologies like renewable energy, hydrogen-based steelmaking, and CCUS, driving the average R&D intensity of related enterprises to increase by more than 35%, and significantly reducing the process carbon intensity as well. In terms of governance enhancement, the disclosure of green bond information, environmental reviews for green insurance, and the construction of ESG ratings have established an external oversight network, prompting enterprises to establish carbon accounting, energy management, and supply chain coordination systems across their value chains. By leveraging raw material substitution, energy efficiency optimization, and process reengineering, they achieve continuous emission reductions. Multi-regional quasi-experimental estimates indicate that when the penetration rate of green finance continues to rise above the 15% threshold, the annual decline rate of corporate carbon emission intensity will jump from 1.8% to 4.3%. Emission reduction actions preemptively implemented by export-oriented enterprises due to carbon tariff expectations will also be significantly catalyzed. Green finance, through the mechanisms of price signaling, technology diffusion, and governance structure optimization, establishes a long-term and systemic effect on carbon emission reduction. It provides a sustainable financial pathway for the low-carbon transformation of industries and the achievement of the "dual carbon" goals.

5. Revelation

5.1 Research Findings

At present, China's economy has transitioned from a phase of high-speed growth to a stage of high-quality development. Promoting the greening of the economy and society is an essential requirement for building a high-quality modern economic system. Green finance, leveraging its advantages in the reallocation of capital elements, can lower the financing threshold for green projects, guide capital flows into green industries, and achieve the development of green finance. Firstly, it is necessary to improve and refine the policy and standard system for green finance to ensure that capital can be accurately and efficiently allocated to sustainable development areas such as green, low-carbon, and environmental protection, thereby stimulating green finance activities and helping enterprises enhance their ESG performance. Promote the replication and dissemination of successful experiences and models from the green finance reform and innovation pilot zones, gradually increase the number of pilot regions for green finance policies, develop and promote innovative green financial products and services, and enhance support for green finance. Secondly, the development of the digital economy has a significantly positive moderating effect on green finance and industrial carbon emission reduction. The spillover benefits brought by the development of the digital economy will more effectively promote the impact of green finance development on industrial carbon emission reduction and optimize the pathways of green finance mechanisms. The government should provide fiscal support and tax incentives for green technology research and development, establish green technology innovation incubation platforms, promote green innovation-driven development, advance the innovation of transition financial instruments, reduce barriers to capital flow, guide funds towards green industries, enhance support for green emerging industries and high-tech

industries, and facilitate industrial structure upgrading.

5.2 Future Research Directions

In the realm of fundamental theories, within the overarching context of the digital economy, traditional resource allocation and risk pricing models struggle to fully account for the profound reshaping of information structures, contract forms, and governance mechanisms brought about by technologies such as blockchain and big data. Future research urgently needs to construct a dynamic general equilibrium model that incorporates digital elements, in order to elucidate how innovations in financial instruments influence the adoption of green technologies by enterprises and the co-evolution of industrial chains through mechanisms such as capital cost, signaling, and network externalities. In the field of innovative mechanisms of financial instruments, current research primarily focuses on established categories such as green bonds and green credit. There is a lack of systematic explanation regarding the risk-sharing, price discovery, and term structure functions of emerging instruments like carbon futures, carbon options, environmental equity pledges, and weather derivatives. In the future, it is necessary to construct a multidimensional analysis framework encompassing risk attributes, liquidity, and incentive compatibility, and to explore their adaptation pathways across different industry life cycles. The construction of localization theory needs to be grounded in China's institutional context, extracting characteristic variables such as local government-led policy innovation, the synergy between the state-owned banking system and industrial policy, and the interaction between regional pilots and central coordination. It aims to establish an institutional economics explanatory logic distinct from the Western market-driven model. At the macro impact level, existing research focuses more on micro enterprise effects, urgently requiring the embedding of green finance variables into endogenous growth models and spatial general equilibrium frameworks. This will systematically evaluate their comprehensive impact on regional economic structure, employment structure transformation, carbon leakage, and fiscal sustainability, building a theoretical bridge connecting micro behavior with macro performance, and providing a panoramic analysis tool for policy evaluation.

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