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Green Finance and Low-Carbon Transformation: The Dual Mediation of Cost Optimization and Technological Innovation under Market Demand Moderation

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ABSTRACT

This study explores how green finance drives the development of green and low-carbon enterprises in China and examines the moderating role of green market demand. Using quantitative methods, data were collected from 404 valid questionnaires covering industrial enterprises of varying sizes, regions, and years of establishment. Structural equation modeling and artificial neural network analysis were employed to test the proposed framework. The findings reveal that green finance significantly supports low-carbon transformation by enabling sustainable practices. Two key mediators—optimization of financing costs and low-carbon technological innovation—play crucial roles in this process. However, increased green market demand negatively moderates the effect of financing cost optimization, while positively enhancing the impact of technological innovation. These results highlight the dual moderating effects of market demand. The study contributes by constructing a hybrid model that integrates green finance mechanisms with low-carbon enterprise development and provides empirical insights based on Chinese industrial data. It underscores the importance of tailoring green finance policies to varying market conditions. Future research may expand on these findings by examining how green finance operates in different industrial contexts or market structures.

Keywords: Green Finance, Low-Carbon Innovation, Green Development, Greenmarket Demand
JEL Classifications: Q56, G20, O31, M21

1. INTRODUCTION

China has pledged to achieve “carbon peaking” by 2030 and carbon neutrality by 2060. In October 2021, the State Council issued the “Opinions on Completely, Accurately, and Comprehensively Implementing the New Development Concept and Doing a Good Job in Carbon Peaking and Carbon Neutrality” and the “Action Plan for Carbon Peaking Before 2030” (Li et al., 2024). These documents aim to promote China’s economic green transformation, adjust its industrial structure, and build a clean, low-carbon, and safe energy system to achieve dual carbon goals (Xu and Mo, 2024).

The industrial sector in China is responsible for the highest proportion of carbon emissions, making it the key area for emission reduction efforts. This is an indisputable fact. Reducing carbon emissions from industrial enterprises is essential for achieving the “double carbon” goal, and the core of this effort is facilitating their shift to low-carbon operations (Hu and He, 2024). However, transformation is not easy. A novel green strategy, changes in production modes, and the implementation of advanced technologies are necessary. More importantly, the low-carbon development model must be realized through industrial chain alliances and upstream and downstream cooperation (Ma et al., 2024). These actions are designed to address every segment of the industrial chain, leading to a comprehensive transformation of the industrial landscape. This will create a more integrated and resilient economic system capable of adapting to future challenges.

The economic growth model of China has undergone significant changes in recent years, with a focus on sustainable development, moving from a focus on speed to a focus on quality (Guo et al., 2024). Judging from the provincial data, this shift is highly consistent with the goal of "double carbon" (Hao et al., 2023). The process of green transformation links sustainable development to the promotion of a more refined and higher quality economic structure. But the question is, how to achieve this goal at the micro level? The traditional extensive development model is obviously no longer applicable. Perhaps only through technological innovation and industrial upgrading can the shift to a low-energy, low-pollution, and low-emission development model required by a low-carbon economy be achieved.

However, this process is full of challenges. Just as technological innovation requires a lot of investment, while industrial upgrading may bring short-term pain. The development of a low-carbon economy is of great importance, as it involves not only the redistribution of economic interests but also a significant shift in social values. In the process of promoting technological upgrading, whether policy support and market incentives can fully mobilize the enthusiasm of enterprises has become the key to success. Previous studies have shown that although green transformation can bring new growth points to the economy, the short-term impact on traditional industries with high energy consumption cannot be ignored (Wahab et al., 2024).

China's industrial structure has long relied on energy and raw materials, with heavy industries such as energy, chemicals, and mineral processing dominating. In 2023, six high-energy-consuming industries contributed 35% of the total value-added of industries above a designated size (Wei et al., 2024). Although strategic emerging and high-tech industries have developed in recent years, their contributions remain low at 25.9% and 12.9%, respectively (Wen et al., 2024). This imbalance limits industrial transformation and hinders low-carbon development. Green technological innovation is crucial for balancing economic growth and carbon neutrality. In the same year, R&D spending reached 101.884 billion yuan, rising by 13.0%. However, weak policy coordination, imperfect assessment tools, and poor technology-process alignment have hindered low-carbon innovation (Wang and Xu, 2024). Achieving the "dual carbon" goal requires substantial investment in energy, industry, construction, and transportation. Expanding ESG investment can improve green financing efficiency, helping address the significant funding gap in low-carbon development (Cao et al., 2024).

Previous studies consistently highlighted green finance as a key mechanism in filling the funding gap to support the low-carbon economy. Financial intermediaries can restrict funding to energy-intensive sectors, encouraging polluting enterprises to transform and innovate (Wu et al., 2024). The impact of government incentives on the flow of funds to ecological activities (Yadav et al., 2024). For example, climate finance policies attract enterprises to participate in energy conservation and emission reduction activities, and promote corporate green innovation, which has been confirmed in empirical data from 4125 companies in China (Liu et al., 2024). Using macro-level panel data and time-series methods (pooled OLS, 2SLS, GMM), it was found that digital financial inclusion promotes economic growth but worsens environmental quality through higher CO_2 emissions (Ozturk and Ullah, 2022). However, how the demand for green markets promotes environmental protection practices is a question worthy of further study.

This study aims to study the mechanism by which green finance affects the low-carbon development of enterprises. A hybrid model is proposed with financing cost optimization and enterprise technological innovation as mediating variables and green market demand as a moderating variable. It is used to clarify whether the moderating effect of green market demand on green finance in promoting green and low-carbon development promotes or hinders the transformation process.

This research discovered that enterprise satisfaction with green finance is beneficial for reducing financing costs and encouraging low-carbon innovation, which promotes green and low-carbon development. Green market demand has a significant positive moderating effect on the impact of low-carbon technological innovation on the enterprises' low-carbon development, but it has a negative regulatory effect on the impact of green finance on financing cost optimization.

This study has made contributions from three main aspects. Firstly, it establishes a brand-new structural model connecting low-carbon development with green finance, presented here serves as a basis for subsequent research in this domain. Secondly, by taking enterprises in China as the research object, this provides direction for finding practical development suggestions for the green and low-carbon industries. Finally, this research enriches the understanding of financial functional mechanisms and offers a fresh perspective on the influence of green market demand within the green finance framework. It uncovers the intricate regulatory role of green market demand in linking green finance supply to sustainable progress in reducing carbon emissions. Although some interactions, such as the interaction between green market demand and green finance, did not produce the expected results, they still significantly promoted low-carbon technology innovation and low-carbon development of enterprises. These findings offer strategic insights for enterprises navigating the low-carbon transition, particularly in balancing market demand, technological innovation, and financing costs. They also serve as valuable theoretical and practical references for policymakers and business leaders.

This article is organized into five parts in the following sections. An analysis of the environmental and financial related theories used and the research hypotheses proposed on this basis will be presented in the second part. The third section introduces the data source and explains the research method and variable setting. In the empirical part of the fourth section, external model analysis, internal model analysis, predictive ability analysis and ANN sensitivity analysis are conducted. The fifth section discusses the results of this study and gives theoretical and managerial contributions.

2. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

2.1. Environmental Kuznets Curve

The hypothesis on the relationship between income inequality and economic growth was put forward by Kuznets (1955). At the stage when the economy is not fully developed, with the economic growth, the income distribution tends to be unequal; When the economy develops to a certain stage, the income distribution will gradually become equal. This hypothesis was later applied by environmental economists to the study of environment and economy and developed into the Environmental Kuznets Curve (EKC). EKC shows that in the early stage of economic development, environmental quality usually deteriorates with the increase in income; but when the income level reaches a certain threshold, the environmental quality begins to improve, showing an inverted "U" relationship (Stokey, 1998). This inverted "U" relationship has been verified in many studies. For example, Dasgupta et al. (2002) propose that pollutant discharge and economic development level exhibit an inverted "U" curve relationship, which could lead to better environmental quality at lower income levels in developing countries. The EKC of three pollutants were verified by using the data from China. It is pointed out that in some cities that have reached the peak, attention should be paid to environmental governance and the environment should not be further deteriorated. Moreover, Shahbaz et al. (2015) confirmed the existence of the EKC in Portugal using time series data from 1971 to 2008. Their study incorporated additional variables such as energy consumption, trade openness, and urbanization into the traditional income-emissions model, and found that while energy consumption and urbanization significantly increased CO_2 emissions, the relationship between income and emissions followed the expected inverted U-shape.

From the data on green patents and carbon emissions between cities in China for 18 years since 2003, an EKC can be obtained. The effects of excessive carbon emissions on GDP are significant and should be carefully examined to ensure balanced economic and environmental policies (Abbas et al., 2024). At present, all provinces are in the rising stage of EKC, and policies should be formulated according to this (Guo et al., 2022). For example, the steel industry is on the rise, and its driving scheme for EKC involves enhancing the output of high-quality, energy-efficient, and high-value-added products (Wang et al., 2022). The technical effect is an important factor driving the decline of the EKC curve (Yin et al., 2015). Data from the top 10 greenhouse gas emitters confirms that economic growth and energy consumption are closely related (Khan et al., 2023). We should consider establishing policies to reduce carbon emissions and ensure economic growth. Such as carbon pricing mechanisms to promote enterprise innovation. The evidence of China is given, and the carbon emissions driven by technology will enter the stage of EKC reduction.

2.2. Transaction Cost Theory

By considering markets and hierarchies, Williamson (1975) first put forward presented the transaction cost theory (TCT) to explain how different governance structures are chosen and their efficiency in economic activities. According to this theory, transaction cost is the core influencing factor in organization and market operation, including the cost of searching, negotiating, supervising and executing contracts. The level of these costs determines whether economic activities are carried out within the market or organization.

The basis of TCT is to analyze the advantages and disadvantages of the market and organization. Anderson (1985) discussed the role of salespeople as external agents or employees, and found that the completeness of contracts played an important role in reducing opportunistic behaviour and supervision costs. Similarly, Yi et al. (2023) analyzed how contract completeness affects transaction costs by reducing active and passive opportunistic behaviours, thus reducing the intention of relationship termination.

TCT has also been widely used in green development and digital transformation. By reducing transaction costs and encouraging technological innovation, digital research has improved the total factor productivity of the manufacturing industry (Wen et al., 2022). The interaction with environmental regulation, however, could lead to higher coordination costs, as businesses must navigate complex regulatory frameworks and ensure compliance. Similarly, Wang et al. (2024) used 10 years of provincial panel data to analyze how Internet development can reduce external transaction costs through market integration. As a result, it leads to improved carbon emission efficiency within the manufacturing industry. TCT links green finance with low-carbon technological innovation. Carbon finance has significantly promoted the green transformation of the marine industry by optimizing financing costs and encouraging low-carbon technological innovation (Xu and Liu, 2023). The environmental performance of enterprises is significantly improved through green supplier integration, which also reduces transaction costs by minimizing inefficiencies and fostering sustainable practices (He et al., 2024). Green supplier integration improves the balance between profitability and environmental responsibility.

2.3. Green Finance and Low-Carbon Development of Enterprises

As EKC emphasizes, driven by technological advances, this shift encourages companies to adopt cleaner and more sustainable production methods (Wang et al., 2022). Green finance emerges as a critical enabler in this transformation, serving as a bridge between environmental goals and economic imperatives. One of its most significant contributions lies in addressing the high financing costs that often deter in low-carbon technologies. Such technologies, while promising substantial long-term benefits, frequently demand significant upfront capital for research and development, along with extended payback periods (Li et al., 2023). Data from 945 listed companies suggest that green finance expands the availability of affordable financing options through the introduction of alternative financing mechanisms such as green bonds, green credit and sustainability-linked loans (Zhang et al., 2021). Green bonds issued by major financial institutions have successfully attracted investors seeking both financial returns and environmental impact, demonstrating the potential of market-driven solutions to align corporate and environmental objectives.

Yet, the challenge of financing risks also cannot be overlooked. High perceived risks often translate into elevated financing costs, further discouraging enterprises from undertaking low-carbon initiatives (Huang et al., 2022). Here, maturation of green finance markets holds a crucial role. By diversifying investment channels and introducing innovative financial products, green finance mitigates risk and lowers the cost of capital. A variety of investors, from institutional funds to individual investors, have been drawn to the rapidly expanding green bond market, highlighting its appeal as a tool for financing environmentally friendly projects. This diversification not only improves market liquidity but also helps reduce borrowing costs driven by competing interests of investors (Cunha et al., 2021). As a result, Hypothesis 1 is proposed.

H_1: The satisfaction of enterprises' green finance needs promotes the optimization of enterprises' low-carbon financing costs.

Green finance, as a financial activity aimed at supporting environmental sustainability, has become a crucial factor in advancing corporate low-carbon transformation, as it aligns financial resources with environmental goals and encourages responsible investment (Xu and Lin, 2024). As global climate change becomes increasingly urgent, low-carbon technology innovation has transitioned from a strategic pathway to an absolute necessity for enterprise survival and competitiveness. Businesses that fail to innovate risk falling behind in a sustainability-driven market. Green finance, by providing essential financial support and innovative financing mechanisms, acts as a catalyst for this transition (Lyu et al., 2024). If green finance can only provide auxiliary funds for enterprises' low-carbon development, its role in achieving the dual carbon goals will obviously be limited.

At the heart of this transformation is low-carbon technology innovation, which includes optimizing production processes, improving energy efficiency, waste treatment and recycling systems (Pimenov et al., 2022). These innovations are not just technical advancements; they represent a fundamental rethinking of how resources are utilized and how value is created. Ali et al. (2023) conducted a survey on green industrial enterprises with more than 10 years of experience and believed that enterprises are constrained by resources. They need to improve product design, logistics, and supervision, enhance resource utilization, and boost enterprise low-carbon efficiency, requiring coordinated resource governance.

From the perspective of Chinese urban data, financial support for low-carbon development comes from the deep cooperation between financial institutions and enterprises. Developing customized financial products targeted at low-carbon development is an important measure to effectively enhance technological innovation capabilities (Yu et al., 2023). However, this has also triggered debates about risk sharing and excessive financial intervention. Consequently, Hypothesis 2 is introduced.

H_2: The satisfaction of corporate green finance needs promotes corporate low-carbon technology innovation.

By combining TCT with EKC, the key role of green finance in promoting the development of low-carbon enterprises becomes apparent (Zhang et al., 2024). Green finance uses its core functions to promote technological innovation and structural transformation, enabling enterprises to achieve economic growth while minimizing environmental impact. Low-carbon technological innovation supports the trajectory of EKC's gradual improvement with economic development under escalating environmental pressure. Green finance, through its resource allocation function, directs funds to low-carbon and environmentally sustainable projects, helping enterprises adopt clean technologies. EKC supports this from a macro perspective (Jiang et al., 2024). Dong and Yao (2024) explored the relationship between urban green finance and residents' environmental awareness, arriving at comparable conclusions. At the micro level, by providing risk management tools similar to green derivatives, green finance helps enterprises cope with uncertainty and deal with potential risks in the low-carbon transition process (Su and Chen, 2024). In addition to green bonds, enhancing corporate environmental performance in the future will also depend on areas such as state-provided incentives and reducing greenhouse gas emissions (Wang et al., 2021). At least from the international price, it can be reflected that green finance is no longer just a policy guide for the government, but has its own market behaviour (Fleschutz et al., 2021). Nevertheless, how green finance specifically contributes to the environmental transformation of manufacturing enterprises in China remains unclear and warrants further hypothesis-driven exploration. In this regard, Hypothesis 3 is suggested.

H_3: Satisfying the needs of enterprises for green finance can have a positive impact on the low-carbon development of enterprises.

EKC demonstrates that environmental pollution initially increases and then decreases, forming an inverted U-shaped relationship during economic development (Huynh, 2024). This theoretical framework is extended to green finance to examine how financing cost optimization affects low-carbon innovation of enterprises. The flourishing of green finance has helped reduce the share of thermal power generation in China's total power generation, demonstrating how financial innovation can support the transition to a low-carbon energy system (Lin et al., 2023). China's power generation industry is set to undergo a low-carbon transformation, dedicating more resources toward advancing and innovating low-carbon technologies.

When facing environmental problems, enterprises often encounter the dual problems of severe financing constraints and limited innovation capabilities. The addition of credit such as P2P has optimized the financing costs of enterprises, and investment in technological innovation has begun to accelerate, thus forming a more dynamic innovation ecosystem (Pan et al., 2021). The advancement of low-carbon technologies is significantly influenced by the optimization of financing costs, as highlighted in this process. Deng et al. (2021) believe that this is accompanied by the regulatory role of taxation. The development of green financial instruments and enhanced financing conditions have significantly broadened enterprises' access to financial resources, accelerated the progress of low-carbon technologies, and facilitated the transition to low-carbon operations. Therefore, hypothesis 4 is proposed.

H_4: The optimization of corporate low-carbon financing costs promotes the innovation of corporate low-carbon technology.

TCT emphasizes minimizing the costs associated with economic exchanges, including information collection, negotiation, and execution. Reducing these costs within low-carbon financing frameworks can substantially boost the efficiency and effectiveness of green investment initiatives. Financing cost optimization improves capital efficiency by alleviating the capital pressure faced by enterprises. Dong et al. (2023) emphasized the importance of optimizing trade credit and asset securitization financing in carbon emission reduction supply chains. Their results show that streamlined financing mechanisms can reduce transaction costs, enabling enterprises to allocate resources to low-carbon initiatives more effectively. The data of 235 prefecture-level cities and the micro-data of NEEQ listings confirm digital inclusive finance reduces information asymmetry and financing barriers for SMEs, thereby reducing transaction costs and promoting sustainable green innovation (Wang et al., 2023).

Well-designed financial instruments can mitigate the transaction costs associated with carbon emission reduction projects, which arise from the synergy created by carbon emission trading and green finance policies (Xiufan and Decheng, 2024). This synergy encourages enterprises to adopt cleaner technologies and practices. Guo and Polak (2024) used Alibaba's intelligent finance case data to highlight the role of financial centralization in reducing administrative and operational costs, which is consistent with TCT because it makes low-carbon financing more accessible and affordable to enterprises. Optimizing low-carbon financing costs through mechanisms such as digital finance, asset securitization, and policy coordination can reduce transaction costs and create an environment conducive to low-carbon development. Therefore, Hypothesis 5 is suggested.

H_5: The optimization of low-carbon financing costs promotes the low-carbon development of enterprises.

The importance of low-carbon technology innovation in driving the low-carbon development of enterprises is widely acknowledged. With the acceleration of global green transformation, enterprises have adopted low-carbon technology innovation as a key strategy to enhance competitiveness and achieve sustainable development (Wu et al., 2024). Many positive outcomes have been documented in existing research on the influence of low-carbon technology innovation on enterprise low-carbon development. Li et al. (2021) got 438 valid data from China manufacturing companies illustrate that low-carbon technology innovation not only advanced the overall performance of enterprises by developing green core capabilities but also significantly improved the environmental performance of Chinese manufacturing enterprises. According to system dynamics research, low-carbon technology innovation contributes to the sustainable development of enterprises by reducing carbon dioxide emissions and improving low-carbon benefits (Zhang et al., 2021). These findings stress the significance of low-carbon technology in enabling enterprises to achieve long-term growth and sustainability in a low-carbon economy.

Using microdata from Chinese enterprises, it is concluded that green credit policies can effectively promote low-carbon technology innovation. These policies provide crucial financial support for enterprises, enabling them to invest in the research, development, and application of low-carbon technologies (Chen et al., 2022). Correspondingly, Yang et al. (2023) stressed that digital transformation drives low-carbon technology innovation by enhancing enterprises' dynamic capabilities. This improvement in absorption, innovation, and adaptability leads to faster research, development, and implementation of low-carbon technologies, supporting sustainable growth. Therefore, low-carbon technology innovation is not only an inevitable response for enterprises to environmental challenges but also an important strategy for achieving low-carbon development. Therefore, hypothesis 6 is proposed.

H_6: Low-carbon technology innovation promotes low-carbon development of enterprises.

2.4. Green Market Demand and Low-Carbon Development of Enterprises

The concept of green market demand encompasses the rising consumer and business preference for eco-friendly and sustainable products and services (Rex and Baumann, 2007). As environmental problems intensify, consumers increasingly value green products, which has led companies to place greater emphasis on environmental protection and sustainability in their production and innovation efforts. Green market demand not only drives companies to pursue green innovation but also promotes the adjustment of policies and management practices, further accelerating low-carbon transformation and the development of a green economy.

Afum et al. (2023) pointed out that green market demand can encourage companies to implement more sustainable financial practices. When green market demand is strong, companies usually pay more attention to green financial instruments because green finance often provides more favorable financing conditions and reduces financing costs. The demand for green products usually signals to financial institutions that the company is in a fast-growing sustainable field, thereby reducing the perception of financial risks (Chen et al., 2024)

Cui and Wang (2022) demonstrated that external green market pressure encourages companies to adjust their innovation strategies in accordance with sustainable development objectives. Against the backdrop of strong green market demand, companies are incentivized to innovate low-carbon technologies because these innovations can not only help companies meet environmental regulations, but also cater to the growing demand for green consumption. Green finance can encourage enterprises to invest in low-carbon technology research and development, which is often difficult to achieve when financing costs are high (Zhang et al., 2023).

Consumer preferences in green markets promote enterprises' commitment to low-carbon development as a long-term strategic goal (Soomro et al., 2023). The authors confirm this using 192 available samples of perceptions of green innovation. Driven by the growing demand for green markets, enterprises are increasingly pursuing green finance to allocate more resources towards low-carbon development initiatives, including the adoption of renewable energy, enhanced energy efficiency, and the optimization of sustainable supply chains. By meeting the financial needs of enterprises, green finance is further strengthened by green market demand, which boosts its effectiveness in helping companies achieve their long-term low-carbon development targets (Negi et al., 2023).

The existence of green markets accelerates the inflow of green finance, optimizes financing costs and promotes green innovation (Xue and Wang, 2024). As green market demand increases, companies can access more favorable financing conditions through green finance channels, allowing them to allocate more resources to low-carbon technology innovation. The optimization of financing costs enables enterprises to focus funds on innovation and research and development, especially in the application of low-carbon technologies. Strong green market demand has driven companies toward low-carbon innovation, while the combination of green finance and market demand has further accelerated the development and promotion of green technology (Chen and Liang, 2023). Based on this, Hypothesis 7 is formulated.

H_7: The green market demand moderates how enterprises' demand for green finance affects the optimization of financing costs (a), low-carbon technological innovation (b), and low-carbon development (c). It also moderates the relationship between financing cost optimization (d), low-carbon technological innovation (e), and enterprises' low-carbon development. Furthermore, the green market demand influences how financing cost optimization (d) and low-carbon technological innovation (e) impact enterprises' low-carbon development.

This study integrates the above assumptions to develop the research framework presented in Figure 1, drawing on the EKC and TCT.

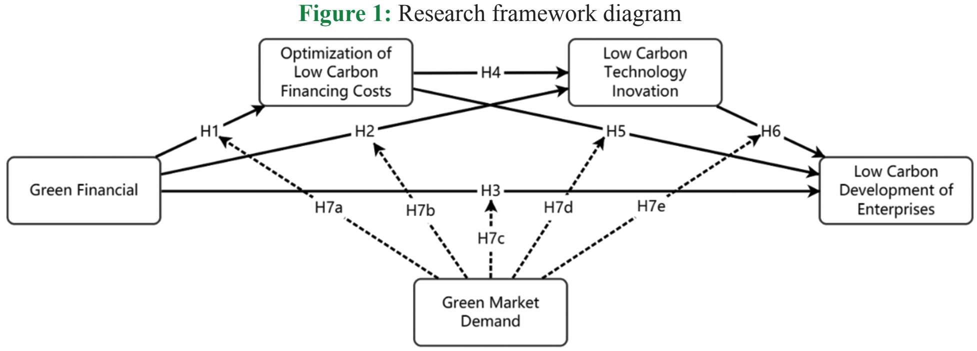
3. METHODOLOGY

This study focuses on the green and low-carbon practices of manufacturing enterprises, highlighting the stability of the industrial system and its robust risk resistance. In 2023, the added value of industrial enterprises in Henan Province above a designated size increased by 5.0%. With a strong industrial base and a leading position in the central and western regions, its industrial added value ranks fifth nationwide. As the economic structure improves, the service sector has played a key role in economic transformation, contributing 63.1% to GDP growth and accounting for 49.1% of GDP. The equipment manufacturing industry has grown rapidly, with a 15.2% increase in added value, boosting advanced and sustainable manufacturing (Zhang et al., 2025). This study selects manufacturing enterprises in Henan Province as the sample, focusing on financial personnel to ensure respondents possess relevant knowledge of corporate finances.

By utilizing SmartPLS4.0 software, this research examines the link between green financial demand and corporate low-carbon development, investigates the mediating roles of low-carbon technology innovation and financing cost optimization, and empirically tests the moderating influence of green market demand. First, descriptive statistics are performed. Then the reliability, validity and model applicability of the questionnaire are analyzed. Following this, the structural equation model is employed to examine the theory. In the final step, the model's sensitivity is checked to ensure its stability.

All the scales employed are adapted from those previously validated and utilized by experts and scholars. This study was conducted in a quantitative manner using a five-point Likert scale using a structured questionnaire. The need for green finance is expressed in terms of energy efficiency, renewable resources and the green sector (Ronaldo and Suryanto, 2022). Green market demand revolves around the current and expected impact of the product demand market on the environment (Lin et al., 2013; Ronaldo and Suryanto, 2022). Low-carbon technology innovation focuses on the company's production technology innovation (Abdullah et al., 2016; Ronaldo and Suryanto, 2022). Financing cost optimization adopts four aspects: financing cost ratio, financing channel, financing risk and financing chain (Lu et al., 2024; Wandfluh et al., 2016). Carbon footprint, energy consumption, regulations, and training are investigated to explore the low-carbon development of enterprises (Lin et al., 2013; Mensah and Ampofo, 2021). The scale was tested for reliability

Figure 1: Research framework diagram



and validity with a survey of 40 parts, and met the requirements of the survey. In this study, 530 questionnaires were sent to the financial and accounting staff of enterprises in Henan Province, 404 valid questionnaires were obtained after strict screening, and the sample recovery rate reached 76.2%, which met the expected requirements.

4. DATA ANALYSIS

4.1. Statistical Analysis

The respondents' profile information, which includes demographic characteristics, is summarized in Table 1. The respondents' gender distribution highlighted that 82.18% were women, which is in line with the company's structure, where financial roles are mainly held by women. This finding aligns with expectations and reflects the gender dynamics within the organization. From the perspective of the area where the enterprises are located, the areas where the surveyed industrial enterprises are located are mainly urban areas (45.05%) and industrial parks (25.74%). Judging from the number of years of establishment of the enterprise and the number of employees of the enterprise, the sample coverage meets the expected requirements.

Table 1: Sample characteristics

Constructs	Options	Count	Percentage	Cumulative percentage
Gender	Male	72	17.82	17.82
	Female	332	82.18	100
Company location	City	182	45.05	45.05
	Suburbs	52	12.87	57.92
	Industrial parks	104	25.74	83.66
	other	66	16.34	100
Years of company establishment	<5	75	18.56	18.56
	5-10	90	22.28	40.84
	10-15	79	19.55	60.4
	15-20	87	21.53	81.93
	More than 20	73	18.07	100
Number of employees (estimated)	<10	64	15.84	15.84
	10-50	91	22.52	38.37
	50-200	89	22.03	60.4
	200-500	74	18.32	78.71
	More than 500	86	21.29	100
Total	-	404	100	100

4.2. Assessing the Outer Measurement Model

The suitability of the model can be analyzed from the stability of the model and the stability of the structure. The calculated SRMR value of 0.041 is below the threshold of 0.08, and the NFI value of 0.907 exceeds the minimum acceptable value of 0.9. These results collectively indicate that the model fits well, meeting the necessary criteria for a robust and reliable model (Pavlov et al., 2021). The sample exhibits a strong surface correlation between items, as evidenced by a KMO value of 0.937 (Zhao et al., 2018). Referring to the article (Naji et al., 2022), the data were further tested for common method bias. The results of Harman's single-factor method showed that the first feature explained 48.610% of the variance, which is below the 50% safety line (Podsakoff et al., 2003), confirming that common method bias is not a significant concern in this study.

The structural stability of the model can be assessed through Table 2, with the factor loadings, Cronbach's alpha (CA), and AVE values for all variables indicating strong structural validity. For green finance demand (GF), the external loads range from 0.834 to 0.850, which are all acceptable, CA is 0.794, and AVE is 0.708, indicating good structural stability; the external loads of financing cost reduction (LC) are all between 0.908 and 0.922, are excellent values, CA is 0.934, and AVE is 0.836, with good internal consistency and structural validity; the external load of low-carbon technology innovation (LI) ranges from 0.901 to 0.921, are above the threshold, which means acceptable, CA is 0.930, and

Table 2: Factor loading, CA, and AVE

Variable	Abbreviation	Item	Outer loadings	CA	AVE
GF	gf1	It is understood that banks are increasing their investment in the renewable energy sector.	0.840	0.794	0.708
	gf2	More money will be invested in energy efficiency in the future.	0.834		
	gf3	Banks are investing more in the development of the green sector.	0.850		
LC	lc1	Your business has reduced the financing cost ratio	0.915	0.934	0.836
	lc2	Your business has expanded its access to increased financing	0.912		
	lc3	Reduce financing risk for your business	0.908		
	lc4	Your business shortens the corporate financing chain	0.922		
LI	li1	Your company's experimental equipment has a high degree of advancement	0.906	0.930	0.827
	li2	Your company's production equipment has a high degree of advancement	0.921		
	li3	Your company's production process has a high degree of advancement	0.901		
	li4	Your company's low-carbon products have a high level of market share	0.908		
GM	gm1	Your business develops eco-innovations as a response to seeing examples of other companies reducing the environmental impact of their products and processes.	0.829	0.786	0.700
	gm2	Your company develops eco-innovations in response to anticipated future market demand for low-impact products from your customers.	0.840		
	gm3	Your company develops eco-innovations in response to current customer demand for products with low environmental impact.	0.841		
LD	ld1	Your business is reducing the carbon footprint of your company's activities.	0.907	0.919	0.805
	ld2	Your business is reducing the energy consumption of your company's activities.	0.904		
	ld3	Your business is strengthening your company's compliance with environmental regulations.	0.889		
	ld4	Your company is training its employees on energy conservation and environmental protection.	0.888		

GF: Green financial, GM: Green market demand, LC: Optimization of low carbon financing costs, LI: Low carbon technology innovation, LD: Low carbon development of enterprises

AVE is 0.827, indicating good stability. The external loads of green market demand (GM) are between 0.829 and 0.841, with a CA of 0.786, and an AVE of 0.700, indicating that the structural validity is moderate, but there is still room for improvement. Finally, the external loadings of enterprise low-carbon development (LD) ranged from 0.888 to 0.907, which are acceptable, showing a good representation of the variables, CA was 0.919, and AVE was 0.805, indicating excellent structural validity. These findings suggest that all variables in the model demonstrate high reliability and structural stability, confirming the robustness of the measurement model and its suitability for further analysis.

When measuring potential psychological constructs using self-report questionnaires and scales in psychology and social science research, researchers must prioritize sufficient differentiation among variables and well-loaded external structures. These steps are essential to ensure the accuracy and robustness of the measurement model (Abadi et al., 2021). That is the difference between variables, which can usually be examined from the correlation within the variable and the correlation between the variables. The Heterotrait-monotrait ratio (HTMT) is usually used to evaluate this value. The HTMT values of the model, as depicted in Table 3, range from 0.228 to 0.668. All HTMT values are <0.85, and the model has good validity (Dahlquist, 2021). The Fornell-Larcker Criterion evaluates discriminative validity by comparing the mean extracted variance (AVE) of each latent variable with the shared variance between latent variables (Gao et al., 2020). A latent variable demonstrates good discriminant validity if its AVE is greater than its shared variance with any other latent variable. These two methods confirm that the model has strong discriminant validity.

4.3. Inspecting the Inner Structural Model

The result frame diagram is obtained by performing 5,000 operations on the model by Bootstrap, as shown in Figure 2. The direct impact of the model is shown in Table 4. The inner structural model assessment provides critical insights into the hypothesized relationships between constructs, enhancing our understanding of their interactions and significance. Direct effects of GF on LC, LI, and LD are significant, with path coefficients of 0.307 (T = 7.437, P < 0.001), 0.223 (T = 5.200, P < 0.001), and 0.102 (T = 2.323, P = 0.020), respectively. The findings confirm the beneficial influence of green finance on these results, emphasizing its role in fostering environmental and economic progress. Furthermore, the relationships between LC and LI (β =0.382, T = 7.771, P < 0.001), LC and LD (β =0.334, T = 6.820, P < 0.001), and LI and LD (β =0.315, T = 5.860, P < 0.001) are also statistically significant, suggesting strong direct effects.

Table 3: HTMT and Fornell-Larcker criterion

Fornell-Larcker criterion\ HTMT	GF	LC	LI	GM	LD
GF	0.842	0.447	0.492	0.228	0.429
LC	0.385	0.914	0.668	0.589	0.667
LI	0.424	0.623	0.909	0.624	0.673
GM	0.181	0.505	0.534	0.837	0.576
LD	0.368	0.618	0.623	0.489	0.897

Regarding moderating effects, the interaction between GM and GF significantly moderates the effect on financing cost reduction (β = −0.147, T = 3.828, P < 0.001), while the interaction between GM and LI positively moderates the effect on LD (β = 0.138, T = 2.759, P = 0.006). However, the other moderating effects, including GM × GF on LI and LD, and GM × LC on LD, were not supported (P > 0.05). These findings reinforce the structural validity of the model while identifying specific areas for further exploration.

To examine the moderating effect of green market demand, interaction terms combining green market demand with green finance demand, financing cost optimization and low-carbon innovation were established, and the relationship with the target variables was tested, as shown in Figure 3. Define low and high levels as one standard deviation level for green market demand, respectively. To obtain two moderating relationships, the low-level green market demand is defined as the mean minus one standard deviation, and the high-level demand as the mean plus one standard deviation.

4.4. Predictive Relevance, effect Size and PLS Predict

The model's predictive capability was assessed through the evaluation of F^2, R^2, and Q^2 predict values, which together provide insights into both its explanatory power and predictive relevance (Chin, 1998). The F^2 values indicate that GF has a moderate influence on key outcomes such as LC ($F^2 = 0.144$), LI ($F^2 = 0.083$), and LD ($F^2 = 0.017$). This suggests that while GF plays an important role in driving these outcomes, its impact is relatively moderate, particularly when compared to other factors such as LC. LC has a stronger and more consistent impact on both LI ($F^2 = 0.184$) and LD ($F^2 = 0.126$), highlighting its key role in low-carbon transformations. Additionally, LI significantly

Figure 2: Model result graph

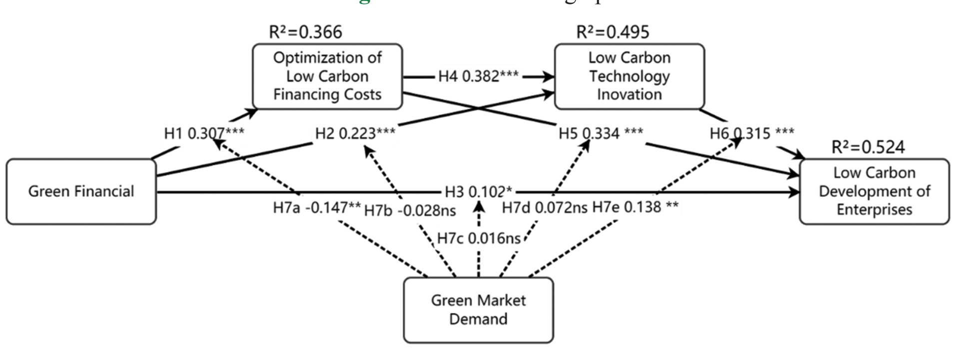


Figure 3: The moderating effect of green market demand on financing cost optimization and low-carbon development of enterprises

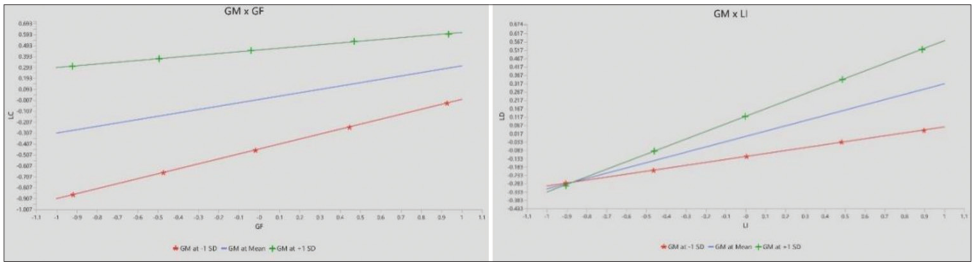


Table 4: Model test results

Hypothesis	Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P-values	Support
H1	GF -> LC	0.307	0.308	0.041	7.437	0.000	Support
H2	GF -> LI	0.223	0.223	0.043	5.200	0.000	Support
H3	GF -> LD	0.102	0.103	0.044	2.323	0.020	Support
H4	LC -> LI	0.382	0.381	0.049	7.771	0.000	Support
H5	LC -> LD	0.334	0.336	0.049	6.820	0.000	Support
H6	LI -> LD	0.315	0.314	0.054	5.860	0.000	Support
H7a	GM×GF -> LC	−0.147	−0.146	0.038	3.828	0.000	Support
H7b	GM×GF -> LI	−0.028	−0.027	0.035	0.784	0.433	Not Support
H7c	GM×GF -> LD	0.016	0.016	0.041	0.402	0.688	Not Support
H7d	GM×LC -> LD	0.072	0.073	0.049	1.468	0.142	Not Support
H7e	GM×LI -> LD	0.138	0.138	0.050	2.759	0.006	Support

Table 5: F^2 R-square Q^2 predict

F^2	LC	LI	LD	R-square	Q^2 predict
GF	0.144	0.083	0.017		
LC		0.184	0.126	0.366	0.353
LI			0.105	0.495	0.390
GM	0.312	0.132	0.020		
LD				0.524	0.316
GM×GF	0.033	0.001	0.000		
GM×LC			0.006		
GM×LI			0.021		

influences LD ($F^2 = 0.105$), indicating that innovation is crucial for broader sustainability goals (Hair et al., 2017, p. 452).

The R^2 values support these findings, with the model explaining a significant portion of variance in key outcomes: LD ($R^2 = 0.524$), LI ($R^2 = 0.495$), and LC ($R^2 = 0.366$). This demonstrates the model's effectiveness in capturing the relationships between variables. The Q^2 predict values also show strong predictive relevance, with LD (Q^2 predict = 0.316), LI (Q^2 predict = 0.390), and LC (Q^2 predict = 0.353), confirming the model's robust forecasting ability.

The results show the model's strong ability to explain and predict, especially for LD and LI. However, areas like interaction effects need improvement for better accuracy. These findings highlight the model's strengths and suggest ways to enhance its performance in future studies. The outcomes align with standard methods in structural equation modeling, confirming the model's validity and relevance, as shown in Table 5.

4.5. Artificial Neural Networking Analysis

Artificial neural networks (ANN) are known for being better at making predictions than SEM (Ciampi and Gordini, 2013; Haykin, 2001). Unlike traditional linear methods, ANN captures complex relationships between variables by modeling them through nonlinear interactions among neurons (Yuste, 2015). This study develops three ANN models based on the significant paths identified in the SEM results, with LC, LI, and LD as the output variables, as shown in Figure 4. By taking advantage of ANN's flexibility and predictive power, this approach aims to offer a deeper understanding of the relationships between the variables in the study. Referring to the (Lim et al., 2021), the sigmoid function is applied as the activation function, so that the model can effectively handle nonlinear relationships while ensuring the smooth progress of the output value.

In order to monitor model overfitting, we imitated the 10-fold cross-validation method used by Aw et al. (2024) and divided the dataset into 10 parts, using 9/10 for training in each iteration and the last 1/10 for testing. By repeatedly evaluating performance on unseen data subsets, this validation technique significantly improves the model's generalization capacity and reduces overfitting risks (Wong et al., 2024). SPSS was used to generate the hidden and output layers of ANN. The sigmoid function was applied to activate these layers. As presented in Table 6, RMSE values ranged from 0.128 to 0.248, consistently low across iterations. This demonstrates not only high predictive accuracy during both training and testing but also indicates the models' resilience to overfitting. The similarity between the mean RMSE values of training and testing datasets provides further validation of the model's reliability and generalizability.

In addition to RMSE evaluation, sensitivity analysis, as presented in Table 7, was conducted to examine the relative importance of each input variable. As shown in Model 1, GM was clearly the most important predictor of LC, boasting an importance rating of 100%. Following GM was GF, which had a considerably lower

Figure 4: (a-c) The model built by ANN

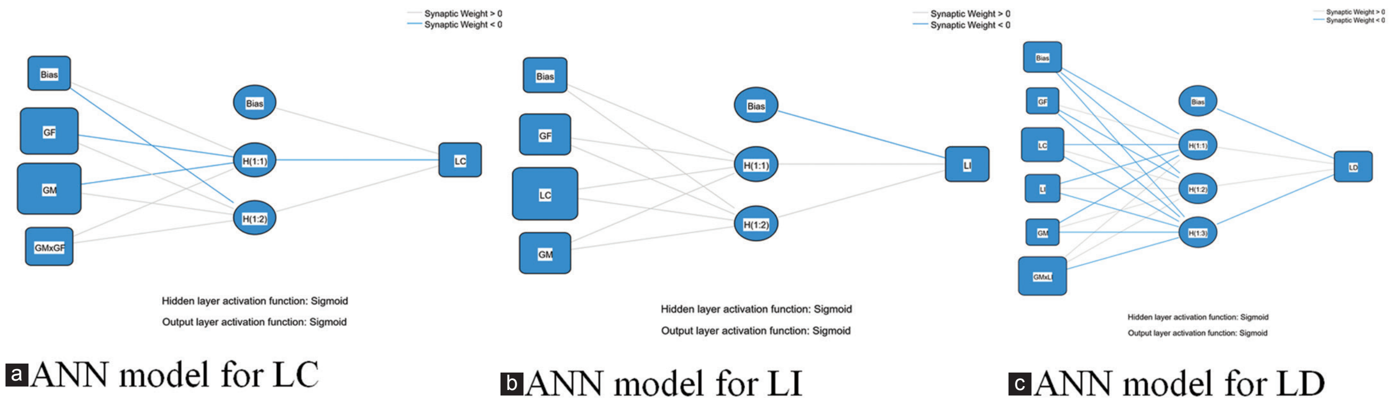


Table 6: RMSE result

ANN	Model 1		Model 2		Model 3	
	Input	GF, GM, GM x GF	Input	GF, LC, GM	Input	GF, LC, LI, GM, GM x LI
	Output	LC	Output	LI	Output	LD
	Training	Testing	Training	Testing	Training	Testing
1	0.221	0.205	0.189	0.201	0.185	0.163
2	0.218	0.222	0.193	0.201	0.187	0.128
3	0.221	0.204	0.191	0.187	0.191	0.149
4	0.217	0.233	0.193	0.197	0.181	0.211
5	0.237	0.235	0.203	0.128	0.197	0.145
6	0.248	0.248	0.195	0.189	0.181	0.189
7	0.228	0.200	0.191	0.189	0.186	0.157
8	0.218	0.231	0.190	0.196	0.179	0.214
9	0.222	0.206	0.195	0.147	0.195	0.201
10	0.218	0.237	0.196	0.139	0.179	0.177
Mean	0.225	0.222	0.194	0.177	0.186	0.173
SD	0.010	0.017	0.004	0.028	0.007	0.030

Table 7: Sensitivity analysis

ANN	Model 1	LC		Model 2	LI		Model 3	LD			
	GF	GM	GM×GF	GF	LC	GM	GF	LC	LI	GM	GM×LI
1	0.358	0.444	0.198	0.261	0.365	0.375	0.081	0.324	0.246	0.136	0.213
2	0.342	0.420	0.238	0.220	0.357	0.423	0.100	0.321	0.222	0.162	0.195
3	0.339	0.479	0.182	0.290	0.324	0.386	0.088	0.334	0.241	0.137	0.200
4	0.348	0.412	0.241	0.270	0.420	0.311	0.006	0.355	0.279	0.143	0.217
5	0.311	0.225	0.464	0.296	0.384	0.320	0.044	0.291	0.238	0.207	0.220
6	0.104	0.415	0.481	0.232	0.361	0.407	0.043	0.301	0.287	0.105	0.265
7	0.242	0.449	0.309	0.282	0.369	0.349	0.059	0.312	0.273	0.088	0.267
8	0.352	0.510	0.138	0.281	0.357	0.363	0.109	0.298	0.208	0.187	0.198
9	0.388	0.539	0.073	0.261	0.355	0.384	0.098	0.292	0.242	0.145	0.223
10	0.343	0.487	0.170	0.277	0.380	0.344	0.054	0.394	0.233	0.121	0.198
Mean	0.313	0.438	0.249	0.267	0.367	0.366	0.068	0.322	0.247	0.143	0.220
SD	0.083	0.086	0.134	0.024	0.025	0.036	0.032	0.032	0.025	0.036	0.026

but still significant rating of 71%. The interaction between GM and GF was also notable, with a score of 57%, further contributing to the overall predictive model. This breakdown highlights the distinct roles each variable plays in influencing LC. Similarly, in Model 2, LC emerged as the most critical factor in predicting LI, with GM also showing substantial influence. In Model 3, LC was shown to be the most important factor in predicting LD.

Moreover, the results from Table 8 highlight a remarkable alignment between the rankings of variables' relative importance derived from the ANN models and those based on structural path coefficients in the partial least squares (PLS) model. This ANN finding strengthens the reliability of the SEM results, highlights how these models can explain low-carbon development, and provides a valuable complementary perspective on the interaction between green finance and market demand. The consistency across models underscores ANN's strong capacity to predict complex relationships, offering valuable validation for its use in forecasting low-carbon transition outcomes. These findings collectively underscore the predictive reliability of the ANN models in capturing the intricate relationships within the low-carbon development context, confirming their utility for forecasting and strategic decision-making in green finance initiatives.

Table 8: Comparison of levels of importance

Path	Original sample (O)/path coefficient	Sem ranking	ANN normalized relative importance (%)	ANN ranking	Match
Model 1					
GF -> LC	0.307	2	71	2	Match
GM -> LC	0.453	1	100	1	Match
GM×GF -> LC	0.147	3	57	3	Match
Model 2					
GF -> LI	0.223	3	73	3	Match
LC -> LI	0.382	1	100	1	Match
GM -> LI	0.301	2	100	2	Match
Model 3					
GF -> LD	0.102	5	21	5	Match
LC -> LD	0.334	1	100	1	Match
LI -> LD	0.315	2	77	2	Match
GM -> LD	0.120	4	44	4	Match
GM×LI -> LD	0.138	3	68	3	Match

5. CONCLUSION, DISCUSSIONS AND IMPLICATIONS

5.1. Discussion

Under the dual carbon development goals, low-carbon development has emerged as a pivotal goal within enterprise strategies to align with sustainable growth imperatives. This research focuses on the effects of green finance on driving low-carbon development, concentrating on two fundamental areas: Enhancing low-carbon technological innovation and refining financing cost optimization. The results of the analysis are presented as follows.

First, green finance plays a crucial role in supporting enterprises, ultimately fostering their low-carbon development and exerting a positive influence. Offering targeted financial support and investment, green finance enables enterprises to adopt strategies that support low-carbon goals. This study's findings demonstrate the significant role of GF in promoting LD, as evidenced by a path coefficient of 0.102 (H_3, $\beta = 0.102$, $T = 2.323$, $P = 0.020$). This shows that green finance encourages enterprises to integrate sustainable practice awareness into production and operation processes, improve resource utilization and bring environmental benefits. Consistent with Bai and Lin (2024), green finance is crucial for low-carbon transformation of enterprises, as it can promote enterprises to adopt innovative environmental technologies. This underscores the importance of green finance in supporting the transition to a low-carbon economy.

Secondly, low-carbon technology innovation is an important driving force for green finance to help enterprises achieve low-carbon development. Green finance supports and helps enterprises give priority to the adoption and implementation of innovative low-carbon energy-saving technologies. The findings indicate a significant effect of LI on LD (H6, $\beta = 0.315$, $T = 5.860$, $P = 0.000$). Green finance supports a broad spectrum of initiatives. This agrees with Bhutta et al. (2022) view that these initiatives are crucial for driving the transition to a low-carbon economy and promoting sustainable development, ultimately supporting the reduction of carbon emissions and the achievement of sustainable development objectives. These technologies include technologies to improve energy efficiency, renewable energy technologies, carbon capture and storage technologies, and more. Green finance enables enterprises to manage the high risks and upfront costs of technology R&D and innovation, speeding up the commercialization process.

Third, financing cost optimization acts as an intermediary factor linking green finance and corporate low-carbon development. Green finance optimizes financing costs and reduces the financing pressure of enterprises with the help of financial products such as green credit and green bonds, so that they can invest in low-carbon projects and environmental protection measures. The results show that LC significantly promotes LI (H_4, $\beta = 0.382$, $T = 7.771$, $P = 0.000$) and supports the LD in a positive way (H_5, $\beta = 0.334$, $T = 6.820$, $P = 0.000$). In addition, GF supports LC in a positive way too (H_1, $\beta = 0.307$, $T = 7.437$, $P = 0.000$), which further promotes the innovation and application of green technology by enterprises. Just like the conclusion drawn from Hu et al. (2021). Green financial products often come with incentives such as government subsidies or preferential interest rates, which decreases the cost of acquiring funds and boosts the willingness and ability of enterprises to invest in low-carbon projects. This reveals that green finance helps enterprises secure more resources for low-carbon projects by optimizing financing costs. The lowered funding barrier facilitates enterprises' more active involvement in green technology innovation and sustainable development.

Fourth, green market demand has a moderating effect on the low-carbon development of enterprises. GM negatively regulates the relationship between GF and LC (H_{7a}, $\beta = -0.147$, $T = 3.828$, $P = 0.000$). When the market demand for green products or services rises, the demand for green financing of enterprises may increase at the same time, but the reduction of financing costs may be limited by the improvement of risk assessment standards for green projects or the intensification of competition in financing channels. When the demand for green market is high, it may be easier for enterprises to compensate for the pressure of financing costs through market income, so the dependence of financing cost optimization on enterprises is weakened. In addition, it may be that the green market demand is too high, attracting a large number of enterprises to enter, and intensifying market competition. Financial institutions may therefore improve financing conditions and increase financing costs. This may also reflect that green finance has certain resource constraints or cost sharing effects when meeting high demand. GM positively regulates the relationship between LI and LD (H_{7e}, β = 0.138, T = 2.759, P = 0.006). High demand means that the market's acceptance and premium ability for low-carbon products and technologies will increase, which will in turn drive companies to increase their investment in the research development and application of low-carbon technologies. Once companies obtain competitive advantages through technological innovation, reaching low-carbon development goals becomes easier for them. This shows that the increase in green market demand can form a "market-driven" low-carbon development mechanism, prompting companies to actively carry out technological innovation and achieve green transformation under the incentive of market signals. Li et al. (2021) also confirmed that innovation advantage is enhanced by the scale of the enterprise. Green market demand is essential for fostering the green transformation of enterprises.

5.2. Theoretical Implications

This study advances the theoretical understanding of green market demand within the green finance framework, illustrating its intricate moderating effects. It demonstrates how green market demand acts as a critical moderating, shaping the relationship between green finance supply and the progress of enterprises toward low-carbon development. Green market demand growth, especially consumers' inclination toward eco-friendly products and services, combined with government policy direction, has steadily become a vital force in pushing enterprises toward low-carbon transformation. Supported by green finance supply, the demand for green markets further promotes enterprises to move towards low-carbon development by influencing their production models and technological innovations.

Although the study finds that the green market demand fails to show the expected impact in some links, such as its inability to significantly regulate the effect of green finance on enterprise low-carbon development. Nevertheless, its contribution to reducing financing costs and advancing low-carbon development is still substantial, underscoring its importance in sustainable business practices. Specifically, the demand for green market has promoted the investment of enterprises in the field of green technology innovation, especially in the commercial application of green technology and the development of low-carbon products, showing a strong market orientation. According to the finding, green market demand does more than just encourage investment in low-carbon technology development. It is also pivotal in boosting the market presence of green products and technologies.

The study contributes theoretically by deepening insights into green finance and market mechanisms interplay, particularly providing fresh support for understanding green market demand's role in connecting green finance with corporate low-carbon development. By clarifying the moderating role of green market demand in the green financial system, the study provides policymakers and firms with key factors to focus on in promoting the low-carbon transition.

5.3. Management Implications

The structural paradigm of green finance's function in enterprise low-carbon transformation is explored in this study. Four suggestions are derived from the practical circumstances of China. First, there is a need for refinement in the existing green finance policy framework. To promote the low-carbon transformation of enterprises, it is necessary to establish and implement a series of green financial subsidy preferential policies, comprehensively plan green credit policies, environmental risk assessments, and green securities regulatory policies, and guide financial capital to flow into green industries.

Second, the ongoing vigorous development of green finance must be maintained. Focusing on the strategic goals of carbon peak and carbon neutrality, planning departments should reduce the risks of financial institutions participating in green financial business and increase their enthusiasm for participation through policy inclinations, risk sharing and other measures. Taking the green finance needs of enterprises as the starting point, financial institutions are encouraged to implement diversified green financial products, help enterprises with environmental protection construction, and provide financial support for the green and low-carbon development of enterprises in China. Provide corresponding technical support and financial support to heavily polluting enterprises to improve their environmental protection capabilities.

Third, the green finance market should be improved and regulated. Define clearer green credit targets to provide a basis for the design and promotion of green financial services. Let more green funds be used for green purposes. Establish a green finance market in each region based on regional differences, and emphasize the coordinated development of regional green. We will build a mobile platform for green finance, increase support for green finance markets in economically underdeveloped regions, and promote the balanced development of green credit among regions, so that it can better play a role in carbon emission reduction.

Fourth, green innovation should be encouraged. Green finance should focus on supporting companies that are committed to the development and adoption of low-carbon technologies and the financing of projects with high content of green and innovative technologies. Financial institutions can encourage enterprises to innovate in areas such as energy conservation and emission reduction technologies, clean energy technologies and carbon capture and storage technologies by setting up special funds and providing loans at preferential interest rates. Provide a good innovation environment for enterprises, including providing R&D subsidies, tax exemptions, intellectual property safeguards, and other policies aimed at reducing risks and costs, which will aid in industrial structure upgrades.

5.4. Limitations and Recommendations

This study, while providing important theoretical perspectives on how green finance facilitates low-carbon development in businesses, has several limitations that should be noted. Although this study provides valuable theoretical insights from a green finance perspective in the field of promoting enterprises low-carbon development, it also has limitations. In particular, the analysis lacks depth in addressing issues such as the representativeness of the sample, variations across different industries, and the nuanced impacts of specific green financial products.

First, the issue of sample representativeness is a limitation of this study. The research data is only from enterprises in China, which means that the conclusions of the study may not be fully representative of the national situation of enterprises. Due to the differences between the economic development level, industry distribution and policy environment of China Province and other regions, the geographical limitations of the sample may affect the generalizability of the research results. Therefore, future studies should expand the sample to cover more regions and industries to enhance the broad applicability of the conclusions.

Second, cross-industry differences are not fully considered. This study does not deeply explore the differences between the low-carbon development of different types of enterprises, especially those in high-polluting and low-polluting industries, with the support of green finance. The differences in resource conditions, technical foundation and development needs of different enterprises may lead to different green financial policies and the actual effects of green financial products. Therefore, future research should consider the moderating effect of industry characteristics on the impact of green finance, especially green finance support and incentives for high-polluting industries.

Finally, the differential impact of specific financial services on corporate low-carbon development has not been fully studied. While a wide range of green financial products exists, including green credit and green bonds, this study falls short of offering a detailed investigation into how these individual products influence the low-carbon development efforts of enterprises in practical applications. Future research should further explore how different types of green financial products affect firms' low-carbon technology innovation and production mode adjustment through different mechanisms, especially the mechanism of product design, financing conditions, policy support and other factors on firms' behaviour.

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