Highlights

Green finance can help enterprises lower carbon dioxide output.

Green finance cut down carbon intensity by optimizing the industry structure.

Green finance lowers corporate carbon output through technological innovation.

Green finance reduces corporate carbon emissions by reducing financing costs.

Green finance lowers carbon discharge through external supervision.

The charm of Green Finance: Can enterprise carbon emissions be reduced by way of Green Finance?

Abstract

The "dual carbon" approach, which emphasizes support for environmentally friendly development and green transition, has reignited passion for green finance. Simultaneously, green finance has progressively emerged as a pivotal approach for addressing climate challenges. The paper develops green finance indicators for Chinese provinces and carbon emission indicators for 2001-2020 A-share listed enterprises. Green financing has been proven to lessen carbon output by upgrading industrial constructure and technological advancement from macroscopical view. On the micro level, carbon emissions can be reduced through three channels: financing effect, innovation effect and external supervision effect. Further research shows that green finance has worse emission reduction results on enterprises in heavy polluting industries and resource-based industries. However, the reduction effect is better for enterprises with high capital intensity and high local marketization level. This conclusion has important guiding significance for the global government on how to achieve the "double carbon" goal through green finance reasonably and effectively.

Key words

Green finance; Enterprise carbon emissions; Financing costs; Technological innovation

1. Introduction

In recent years, the global climate changes abnormally, many countries and regions in the world have appeared very rare high temperature weather and dry climate. The climate environment of high temperature, drought and decreasing rainfall has a great impact on human's happy life and normal economic activities. This extreme weather is the result of human overproduction. Therefore, in order to live in harmony with nature, all countries in the world must follow the green, healthy and sustainable production and development mode. The issuing of the Paris Agreement prompted global efforts to enhance the climate environment. The 26th United Nations Climate Change Conference in 2021 finalized the implementation rules of this agreement. All the countries participating in the meeting said they would actively implement the agreement. Additionally, participating nations have pledged to follow the specific guidelines in order to attain the global objective of "dual carbon." And all countries are actively seeking a green development path that suits their national conditions. As an industrial country, China has also actively participated in climate governance and green transformation. In 2022, global carbon dioxide emissions related to energy saw an increase of 0.9%, totaling over 3.21 billion tons, reaching a new high of over 36.8 billion tons. Out of the added 3.21 billion tons of carbon dioxide, 60 million tons can be attributed to cooling and heating demands during extreme weather conditions. Following two years of unusual fluctuations in energy use and emissions (partly due to the COVID-19 pandemic), the growth in 2022 was significantly lower than the over 6% rebound seen in 2021. Emissions from energy combustion increased by 423 million tons. As depicted in Fig. 1, most countries globally witnessed substantial carbon dioxide emissions in 2022. The release of significant amounts of carbon dioxide and other pollutants has exacerbated the speed and extent of global climate change. The increasing frequency of extreme weather events, rising sea levels, and glacier melting are increasingly evident, posing severe threats to both human society and natural ecosystems.

[Insert Fig. 1 here]

In fact, in the process of China's exploration of emission reduction, the administration has introduced a great many relevant policies. The term "green finance" describes a set of financial practices that support timely allocation of resources, enhance environmental governance, and address extreme global warming. Green finance includes various investment and financing projects.

These programs have strict criteria and requirements for funding and investment aims, benefits, and risk management because they are based on the core objective of green finance. Only companies whose production practices are green and healthy and sustainable will be eligible for these green financing. And green finance can help enterprises and regions to achieve the "double carbon" goal more quickly and accurately. In the realm of green finance, the Porter Hypothesis offers an intriguing theoretical framework. The Porter Hypothesis underscores the positive incentives of environmental regulations on firms, compelling them to adopt more environmentally friendly production methods (Porter & Van-der-Linde, 1995). According to this hypothesis, firms under the pressure of environmental regulations are driven by funds obtained through green finance channels and financial incentives to engage in technological innovation and employ greener production techniques. This facilitates the enhancement of resource utilization efficiency, thereby reducing carbon emissions and achieving sustainable development.

In order to verify this problem, this paper will carry out theoretical and empirical research. It can not only assist users in comprehending the significance and practical applications of green finance, but also provide possible path support for "dual carbon" policy makers.

In today's global context, the development of green finance policies is unfolding at an unprecedented pace. With environmental issues becoming increasingly prominent and the urgent demand for sustainable development, governments and international organizations are actively formulating and promoting the implementation of green finance policies. The introduction of these policies not only reflects the pursuit of environmental protection and ecological balance but also signifies a profound reflection on and transformation of economic and social development models. The rapid development of green finance policies highlights their policy relevance and indispensability in the face of current global challenges. Firstly, as the threats posed by global climate change and environmental degradation to the economy and society continue to grow, green finance policies have become one of the key tools driving economic transformation. Secondly, the urgent need for the improvement of green finance policies is evident. Despite some achievements, there are still many challenges and shortcomings. For instance, constraints on financing for environmental projects within the financial system, lack of uniform evaluation standards, and imperfect market mechanisms hinder the effective implementation and effectiveness of green finance policies. Therefore, this paper argues that research on green finance and policy refinement

are necessary. Only by continuously enhancing the specificity and operability of policies can we better address global environmental and economic challenges, promote sustainable economic and social development, and achieve high-quality economic development.

From the literature, some scholars are keen on the analysis of single products in green finance. As a financial derivative, any type of product in green finance is profitable. Therefore, many researchers have found the economic benefits of green finance for enterprises (Salazar, 1998). This literature mainly includes two aspects. The first is the research on the pricing of green financial products (Flammer, 2021) and the research on the stock volatility when green bonds are issued (Tang & Zhang, 2020). The second is to study the impact mechanism of economic benefits brought by green finance. Its research mainly focuses on two functional paths: reducing financing costs and promoting innovation (Li et al., 2018). Owing to the specific national circumstances of China, the industrialization process is backward, but the development speed is faster, and the development area is wider. Therefore, the demand for green finance with green added value is higher. Enterprises need the financing function of green finance to expand production. In addition, enterprises also need its green function to create a positive social image of taking environmental responsibility. On the one side, the scale effect brought by the financing function of green finance may aggravate pollution; On the other side, the green function of green finance may reduce pollution through improving production efficiency of enterprises. Thus, the matter of whether green finance may improve a company's commitment to sustainability has to be studied immediately.

In this context, it creates an intricate index of province-level green finance in China. The index is matched with the data of listed enterprises for quantitative analysis. This paper conducts empirical research on the impact and pathways of green finance in reducing carbon emissions, selecting data from different levels of enterprises and provinces. Additionally, it selects different data from the perspectives of universality and heterogeneity. After several tests, including limiting sample data, replacing cluster standard error and tailing reduction, the result is still reliable. The theoretical examine displays that green finance can lower the carbon intensity by upgrading industrial structure and improving technological innovation from macroscopical view. Otherwise, enterprise carbon emissions can be reduced through financing effect, innovation effect and external supervision effect from the micro level. Additional examination of variability reveals that the role of green funding on businesses in highly polluting and resource-based industries to reduce pollutants is less favorable.

But green finance has a better carbon reduction utility on enterprises in capital-intensive industries. Furthermore, the more marketized the area, the greater the role of green finance on the enterprise's acting force to lower its CO_2 emissions. The study findings presented in this article have major guiding implications for how green finance is developed and how CO_2 reduction plans are put into practice in China and even in the world.

This research could potentially make the subsequent contribution: First, from a research standpoint, this document investigates the environmental performance of green finance from the viewpoint of microenterprises. And this paper innovatively uses carbon emission index to characterize enterprise environmental performance. Within the framework of advancement focused on economic expansion, most of the research now in publication covers the economic benefits of green financing. Furthermore, most of the research that has been published thus far on the benefits of green finance for sustainable development concentrates on the macroenvironmental elements of these benefits. The environmental benefits of green finance are rarely studied from the perspective of micro-enterprises. Second, in terms of the mechanism of action, this study proposed and evaluated the contribution of green finance to the reduction of enterprise dioxide emissions at both the micro and macro scales. Theories about how green finance can reduce corporate pollution are not comprehensive. Due to the lack of data, most of the relevant studies remain in the stage of theoretical analysis. Third, about the measurement of indicators and the use of data. On the one hand, this paper innovatively uses green finance products to build a comprehensive index. At present, most literature only uses an indicator to characterize green finance. However, a single indicator cannot adequately describe the overall characteristics. On the other hand, this study uses information such as industry average cost, industry energy consumption, and enterprise income and cost to indirectly assess the carbon dioxide emissions of enterprises. It offers empirical support for the study of the effectiveness of green financing in lowering carbon emissions. Fourthly, at the policy level, green finance policies possess significant policy implications and irreplaceability in the current context, characterized by rapid development yet requiring continuous improvement and reinforcement. This paper investigates green finance from the perspectives of universality and heterogeneity, proposing policy recommendations tailored to green finance across different industry sectors. It is only through further enhancing the effectiveness and adaptability of green finance policies that sustainable socioeconomic development goals can be better achieved.

The remainder of this research's materials are arranged below: The theoretical mechanism and literature review are covered in the second portion. Model setup, index measurement, and data facts are covered in the third section. The outcomes of the empirical analysis are shown in the fourth section; The fifth section conducts mechanism testing and heterogeneity analysis. Finally, the sixth section concludes the conclusions and recommendations.

2. Literature review and mechanism analysis

2.1 Literature review

In theory, green finance is an economic behavior related to green development that is supported by the national government and implemented by the financial sector. In this kind of economic behavior, environmental governance should always be taken as the basic direction. In the process of production, investment and financing, we must always consider whether it can bring positive environmental benefits. The first studies of green finance date back to the 1990s. Relevant theories indicate that green finance can establish a close connection between economic development and environmental protection upon market entry, thereby fostering economic growth and facilitating the achievement of sustainable development simultaneously (Salazar, 1998). This sort of study lacks an empirical basis and focuses mainly on the qualitative analysis of green finance. Furthermore, most of the previous research examined the pivotal function of financial organizations in the context of environmentally friendly growth (White, 1996; Jeucken & Bouma, 1999). Recently, with the increasing attention of the international community to ecological protection and green development, green finance has received renewed attention. However, the majority of research projects continue to investigate how green finance affects tiny enterprises' economy. Relevant research has demonstrated that, once on the market, green financial products can successfully foster financial markets' economic growth (Climent & Soriano, 2011; Sachs et al., 2019). Based on this premise, Zerbib (2019), Larcker & Watts (2020), Tang & Zhang (2020), and Flammer (2021) conducted further investigations into the pricing of green productions, revealing a significant enhancement in the environmental rating of issuing companies. Enterprises with higher environmental ratings will also have more financing facilities (Sharfman & Fernando, 2008; Ioannou & Serafeim, 2015). Then the financing cost of enterprises will be reduced (Zhang et al., 2021), enterprises' degree of environmentally conscious innovation is going to increase (Li et al., 2018) and economic growth

will be promoted (Markandya et al., 2015; Ruiz et al., 2016; Zhou et al., 2020). In addition, according to an investigation of Chinese and American data, He et al. (2019) also found that green finance helps boost enterprises' efforts to carry out studies and experiments on green technologies.

Another type of literature related to this paper is corporate carbon emissions. Carbon emission has always been one of the topics widely concerned by all mankind. In the near future, if enterprises want to seize market share and gain the support of the public and all sectors of society, they must ensure that their carbon emissions are strictly controlled. It can be said that the carbon emission index of enterprises can let all sectors of society see the social responsibility and management efficiency of enterprises in environmental issues. Numerous facets of the influencing elements of business carbon emissions have been examined in pertinent research. On a macro level, some scholars have studied the impact of regional environmental regulation (Shapiro & Walker, 2018; Fan et al., 2019), Government intervention (Henriques & Sadorsky, 1996; Zhang et al., 2022), Market competition (Duanmu et al., 2018), technological change (Acemoglu et al., 2012; Huang et al., 2022), the construction of carbon emission trading market (Hu et al., 2019), carbon tax policy (Barrage, 2020), and international trade (Shapiro, 2021) on carbon outputs. On the micro level, some scholars have also studied the impact of many microscopic factors such as the level of corporate governance (Lewis et al., 2014; Endo, 2020; Van Hoang, 2021), economic performance (He et al., 2016), enterprise ownership (Bai et al., 2006; Wang et al., 2022) and executive team competence (Lewis et al., 2014; Zhang et al., 2020) on corporate carbon outputs.

A great deal investigation has been done on the financial implications of green-finance and the determinants of corporate emission rates, in conjunction with the pertinent literature on the subject previously discussed. Nevertheless, the implications mechanism of green finances on enterprises greenhouse gases has not yet been studied in these investigations. Furthermore, most green finance research centers around a specific green financial product, and not many individuals create a thorough index of green finance. Existing literature on green finance primarily focuses on green credit and green bonds. However, from a macro perspective, a single green financial product cannot fully represent green finance. Moreover, most scholars are inclined to study the financing advantages that green credit and green bonds bring to enterprises, as well as the path analysis of how green credit promotes socio-economic development. In contrast, our study examines the impact and pathway of comprehensive green finance indicators on enterprise carbon emissions, with a

particular emphasis on analyzing the environmental benefits brought by green finance to enterprises. Additionally, environmental pollution-related literature shows that existing studies explore energy-saving and pollution-reducing factors from various dimensions such as government policies, market interventions, and corporate governance. Some scholars also integrate the concept of environmental degradation with economic complexity to study global sustainability (Atif et al., 2022; Meysam et al., 2022; Daniel et al., 2023). However, there is scarce research from the perspective of green finance on the environmental benefits it brings to enterprises. To compensate for the research shortcomings, this study analyzes the association throughout enterprise emissions of carbon and green financing for the first time. In addition, this paper further proposed and tested their mechanism of action.

2.2 Theoretical analysis

Based on the results of literature review, this section will further analyze the function of green financing on reducing corporate carbon emissions from both macro and micro aspects.

Macroeconomically speaking, there are three ways that green finance may lower the carbon dioxide emission of enterprises:

First, Green finance can lower corporate carbon output by upgrading local industrial structure. Green finance has the potential to accelerate the tertiary sector's growth and encourage the modernization of the industrial framework. Tertiary industry usually refers to industries other than primary industry and secondary industry. The secondary industry includes heavy industry with significant pollution. Clean industries such as information and services in the tertiary sector have easier access to green credit than heavy industries, which are more energy intensive. It is also easier for such industries to raise money by issuing green bonds. Therefore, green financing could support the third-party industries' growth and make the industrial structure's modernization easier. Furthermore, a fundamental aspect of upgrading industrial structure involves enhancing the value-added attributes of products. The use of green finance can redirect production factors and resources towards industries with higher production technology and better management models, while reducing energy usage and pollution levels. Advanced production technology and management mode can make the added value of the enterprise's products rise a level, thus forming a more sophisticated manufacturing system. From another perspective, the upgrading of industrial framework will make the industry shift from the traditional operation model to the new production

and operation model. The new production and operation mode can achieve the effect of reducing the carbon emission of enterprises. The new production and operation mode can make efficient use of production factors and realize effective allocation of resources (Eremia & Stancu, 2006). The utilization of production factors in the production process is enhanced, enabling enterprises to maximize their efficiency and productivity. It significantly lowers the rise in pollution and resource waste brought on by nascent technology or resource incompatibility.

Second, Green financing can boost regional innovation and hence lower enterprise carbon emissions. Green finance has the potential to raise local technological innovation levels, on the one side. Productivity largely depends on the degree of technical innovation, and increasing technological advancement can result in a significant increase in productivity. Especially with the advent of the era of knowledge economy, the level of technological innovation has an unshakable position in the market competition in today's society. In order to meet the national environmental governance standards, various provinces in China will actively introduce green finance in their own provinces. The implementation of green finance needs the promotion of government policies. The administration is going to provide specific green subsidies and incentives to enterprises who actively utilize items related to green financing. To enable enterprises to obtain green finance more smoothly, the government will increase financial investment in technological innovation. To raise the general standard of regional innovation, the government can establish a platform for green technology advancement inside the province. Additionally, the upward trajectory of the technical innovation degree in the whole area will boost the innovation capacity of enterprises in the area as a whole owing to the functions of the agglomeration economy and scale economy. The degree of regional technological innovation can continuously provide energy for local enterprises. Additionally, regional enterprises will profit from technological advancement to a greater degree as it advances. After the technological innovation level of enterprises is improved, the emission reduction technology can also be improved simultaneously, and enterprises' dioxide emissions will be lowered.

From a micro viewpoint, green finance can lower corporate carbon intensity in the following three mechanisms:

First, Green finance can lower financing costs, which in turn can lower corporate dioxide emissions. From the perspective of enterprise financing, green finance entering the market can

lower the financing cost of enterprises. Green finance includes various financial products. The purpose of these financial products is to support the financing and operation of green projects. For enterprises, the premise of developing production is to obtain financing. If they want to obtain financing for green financial products, they must meet the environmental threshold required. Enterprises which consume plenty of power and produce a great deal of pollutants need to enhance their environmental performance to be eligible for the credit support of green financing. When enterprises meet the environmental access conditions required by green finance, they will show a better environmental image to the market and gain a higher social reputation. The improvement of corporate social reputation will attract more investors, thus obtaining financing facilities (Ioannou & Serafeim, 2017) and reducing financing costs (Zhang et al., 2021). On the other side, green financing lowers the financing cost, and the working capital increases accordingly. The enterprise can put the excess working capital into other production and business activities, and further improve the benefit level. The improvement of corporate profitability not only directly increases corporate profits, but also increases the investment of enterprises in R&D. Thus, the carbon emissions of enterprises can be reduced.

Second, Green funding encourages technological innovation, which lowers enterprise dioxide emissions. From the perspective of the production process of enterprises, the total carbon emissions can be reduced by controlling the production source. Additionally, the effective management of production termination is crucial. The enterprise's commercial choices are linked to the management of the production source. But the management at the end of production needs more technical support. On the one hand, to obtain green financing, enterprises will spontaneously improve their innovation ability and upgrade emission reduction equipment to achieve environmental access conditions for green financial products. At the same time, enterprises also benefit from easy access to finance through green financing, which reduces their financial limitations and boosts operating earnings. On the other hand, the increased profits provide strong financial support for enterprises' green innovation. Through the creation of green science, companies may optimize their production and decrease emissions from equipment. Enhancing the efficiency of industrial machinery can lower the release of pollutants at the stage of production and increase the rate at which resources are utilized. The optimization of emission reduction equipment can more accurately identify and screen pollutants. More sophisticated equipment differentiates the

treatment of pollutants with different chemical properties, thereby reducing the carbon emissions of enterprises in the end treatment.

Third, Green financing has the potential to lower corporate carbon emissions by raising the standard of external supervision. On the one hand, from the perspective of the business process of enterprises, the level of environmental governance is closely correlated with the decision-making of enterprise management. The ability of enterprises to obtain financing through green finance will convey to the market the message that enterprises are willing to undertake social and environmental responsibilities (Dhaliwal et al., 2011). This will make it easier to attract value-focused institutional investors in the market to increase their holdings in the company (Tang and Zhang, 2020). Such institutional investors are usually more professional and rational than retail investors in the market. They keep track of corporate information and keep an eye on environmental decisions. Under the supervision of these institutional investors, the short-sighted behavior of corporate management has been greatly reduced and the agency costs for shareholders have been reduced. On the other hand, the decline in enterprise agency costs will lead to the flow of spare funds into the R&D of emission reduction equipment, thereby reducing enterprise carbon emissions. Simultaneously, the enterprise will have additional departments and individuals responsible for monitoring its pollution outputs under external oversight. This allows them to regularly develop policies to reduce emissions, thereby reducing the carbon emissions of their companies.

[Insert Fig. 2 here]

3. Index measurement and typical facts

3.1 Model setup

This report aims to look into the link between corporate carbon emissions and green finance. Therefore, this paper chooses a multi-dimensional fixed effects model to analyze the research direction. The specific econometric model is as follows:

$$\ln intencoo_{ijt} = \alpha_0 + \alpha_1 green_{jt} + \varphi X_{jt} + \eta Y_{ijt} + FE_{pro} + FE_{year} + FE_{indu} + FE_{indi} + \varepsilon_{ijt} \quad (1)$$

The symbols *i*, *j*, *t* stand for enterprise, province, time, in that order. The explanatory variable *intencoo* represents EIC carbon emission index. The degree of advancement in green financing is reflected in the central explanatory variable (*green*) in this paper. The control variable for the

province is defined by X, and the control variable for the enterprise is defined by Y. FE_{pro}, FE_{year}, FE_{indu} and FE_{indi} represent province, year, four-digit industry and individual fixed effect respectively, α_0 is the constant term, ε_{ijt} is the random error term, α_1, φ, η is the regression coefficient.

3.2 Index measurement

(1) Green Finance Index (*green*). Green financing serves as this article's primary explanatory variable, and the indicator adopted is the provincial green finance Index from 2001 to 2020. This paper draws on the definition and scope of green finance outlined in the *Guiding Opinions on Building a Green Financial System* jointly issued by seven ministries and commissions including the People's Bank of China and the Ministry of Finance. Considering data availability, this study has constructed a comprehensive green finance index aligned with the research direction of this paper based on relevant literature (Chi & Chien, 2022; Ran & Zhang, 2023; Liang & Yang, 2024). The measurement system is as follows: This paper selects four green finance indicators, including credit, investment, insurance of green and government support, to build a comprehensive index. Among these, the interest paid by energy-intensive enterprises is referred to as green credit. Specifically, Green credit is articulated in terms of the scale of the interest cost of the six energy-consuming industries[1] in the total industrial; Green investment is expressed as the proportion of environmental pollution control investment in GDP. The percentage of interest that is charged by the six consuming energy industry percent to the as a whole sum of mortgage charged by factories is how green credit is determined. All of this data was gathered from the China official database of each of China's thirty provinces (except from Tibet). This research establishes the entire index of green finance applying the entropy approach. It is a measure of the uncertainty of the index. In general, the greater the amount of information that an index can represent, the smaller the entropy and the smaller the uncertainty.

This paper uses the calculated green finance data to draw the evolution trend in 2001 and 2020, as shown in Fig. 3. As can be seen from the figure, from 2001 to 2020, the situation of green finance growth has improved to varying extents in most provinces, especially in the southeast and coastal regions. The southeast and coastal regions may have had greater levels of commercial and cultural growth, which could be the cause. Enterprises in these regions are more willing to obtain green

[1] Oil processing, coking and nuclear fuels processing, chemically materials and manufacture of goods, non-metal substances, ferrous metals making and the rolling processing, non-ferrous metal making and rolling processing, and the manufacturing and supply of electric heat and power are high energy-intensive industries.

finance, and green finance development is better.

[Insert Fig. 3 here]

(2) Enterprise carbon emission intensity (*intencoo*). In this article, the enterprise carbon output is the explained variable. A company's carbon intensity is closely related to its carbon content, but most companies in China do not disclose their carbon dioxide emissions directly. An enterprise's key trade is correlated with its carbon outputs. To describe the share of the organization's carbon emissions to the overall carbon emissions of the industry, this article uses the enterprise's substantial trading costs in a percentage of the industry's core enterprise's total costs. The carbon emission data of enterprises in this paper are derived from the annual reports of Chinese A-share listed companies from 2012 to 2020. Due to data availability constraints, the carbon emission data of enterprises in this paper is only available up to 2012 (Shang et al., 2023). Therefore, this paper matches the comprehensive green finance index data from 2012 to 2020 with the data on corporate carbon emission intensity, and conducts empirical research based on this matching.

Research on carbon emissions of Chinese listed companies primarily involves two main categories of indicators. The first category directly utilizes publicly disclosed carbon emissions data. However, only a portion of listed companies disclose carbon emissions data in their annual reports, leading to issues of incompleteness, insufficiency, and feasibility. The second category of indicators is derived from the first category and is applicable to companies that have not disclosed their carbon emissions. It mainly involves the indirect conversion of different types of fossil energy usage data, including electricity consumption, power consumption, and heat consumption. In this paper, we adopt the second category method, approximating the carbon intensity of enterprises by industry carbon emissions and total energy consumption of Chinese listed companies (Shang et al., 2023). Specifically, this involves measuring the ratio of carbon dioxide emissions to main business revenue (Pan et al., 2024). This method aims to address the data gaps and feasibility issues in the first category of indicators, thereby providing a more comprehensive assessment of the carbon emissions of Chinese listed companies.

In this article, the industry's carbon emission is initially calculated as the mass of carbon

dioxide (TEC×2.493) divided by the entire energy expenditure of the industry whereby the enterprise is located. The percentage of the company's primary operating expenses to the industry's operating expenses ($\frac{cost\_f_{it}}{cost\_i_{dt}}$) is used to approximate the share of the enterprise's carbon dioxide emissions in comparison with that of that industry. Through the above data, the enterprise carbon emission (*em*) can be estimated indirectly, as shown in equation (2):

$$em_{it} = \frac{cost\_E_{it}}{cost\_I_{dt}} \times OEC_{jt} \times 2.493 \quad (2)$$

Then, this paper measures enterprise carbon emission intensity by dividing enterprise carbon dioxide emission by main business income (Shang et al., 2023). The accurate formula for computation goes as below:

$$intencoo_{it} = \frac{em_{it}}{income\_E_{dt}} \times \frac{1}{1000000} \quad (3)$$

The enterprise's primary commercial expense is denoted by *cost_E*, the industry's primary commercial expenditure is shown by *cost_I*, and the primary comercial income is indicated by *income_E*. The industry is symbolized by *d*. *OEC* is a depiction of the industry that the company plays in's overall energy consumption. One ton of standard coal has a carbon dioxide exchange index of 2.493, which is mostly based on the carbon dioxide benchmark provided by the Xiamen Center (Lin & Jia, 2019). The data of energy utilization are from China official database.

(3) Control variables. In order to minimize the possibility of prejudice resulting from missing elements, particularly in reference to the existing literature (Amore & Bennedsen, 2015), this paper controls 9 characteristic variables at the enterprise-level: Among them, this paper refers to the common variables used in the relevant literature, including corporate size (ln*size*), the cash flow ratio (*cflow*), the extent of concentration in power (*top10_HHI*), the number of years listed (ln*age*). In addition, according to the status of the enterprise, this paper selects indicators that can measure the use of enterprise assets and profit status, including Asset-liability ratio (*lev*), return on assets (*roa*). In addition, to prevent omissions, the following control variables are added. The enterprise type (*govcon_p*) attribute indicates if the enterprise is owned by the government or not. This variable is defined as 1 if the enterprise is government ownership and 0 if it is not, based on the real administrator and share type of the enterprises. The rate of expansion of the overall assets can be calculated by the growth rate (*tagr*). The status of two positions (*nonindep*) indicates that there is a situation in which directors concurrently serve as the management level of the enterprise, that is,

directors of the enterprise have control rights within the enterprise. *nonindep*=1 if the director is also the management of the company, and *nonindep*=0 if the director is independent of the management of the company. This paper investigates the impact of green finance on corporate carbon emissions. To eliminate interference from other factors on this result, the study effectively controls variables that may influence the research outcome at both macro and micro levels. From a micro perspective, the paper mainly considers variations in enterprise size, age, nature, and operational conditions, as different enterprises may have varying pollution emissions and intentions to adopt green finance. Therefore, representative variables were selected from these aspects for the empirical study. Additionally, at the macro level, the study focuses on provincial-level variables. Due to differences in policy orientation, economic markets, and geographical advantages among provinces, the introduction of green finance may have varying degrees of impact, potentially resulting in bias in the research results. Therefore, the study controls for the environmental regulatory level of the region from the policy orientation perspective, the degree of external development, and employment density from the economic market perspective, and energy consumption from the geographical advantage perspective. This is mainly because regions with favorable geographical advantages and mineral resources tend to incubate many high-consumption enterprises, leading to more severe pollution emissions. Hence, the paper controls the level of regional energy consumption to reduce bias in empirical research. In addition, this paper controls four characteristic variables at the provincial level: The openness of a province (*open*) represents the degree of foreign trade of the province, measured by total import and export trade divided by gross domestic product. Provincial energy intensity (*EP*) represents the energy consumption of each province, as measured by total energy consumption as a percentage of GDP. Employment density (*ED*) is the ratio of the overall quantity of working individuals to the area of the administrative territory, and it represents the industrial concentration density of each province. The Environmental Regulation Index (*ER*) indicates each province's grade of environmental policy. According to the median environmental regulation level of each province, if the environmental supervision degree for the province where the enterprise lives is higher than the median, then (*regu*=1), otherwise (*regu*=0).

3.3 Data facts

(1) Descriptive statistics of data.

The major sample utilized for this article is data from China's listed public enterprises. The sample data are handled in this way: (1) The enterprise samples for ST and *ST are not included; (2) Eliminate the sample with serious missing financial data or other key data; (3) Data of enterprises with net assets less than 0 are excluded; (4) The data of financial and real estate enterprises are excluded; (5) The number of employees, industry category, year of operation and sales of 0 or less or missing data are excluded. The CSMAR database provides the corporate relevant data needed for this article. Finally, 16,695 data covering 2628 listed enterprises during sample period were acquired. Table 1 displays the findings of the comprehensive mathematical analysis.

[Insert Table 1 here]

(2) Correlation analysis.

In order to preliminarily express the research significance of this subject, this paper drew the scatter-linear fitting diagram of binscatter, as shown in Fig. 4 (a). In consideration of the great deviation of enterprise data in 2020 in light of the repercussions of the new coronavirus epidemic, this paper deleted the data of 2020 for plotting, as shown in Fig. 4 (b). China's four major municipalities have more advantages in economic development than other provinces. Therefore, the data of the four major municipalities were deleted and the scatter-linear fitting graph was drawn, as shown in Fig. 4 (c). Fig. 4 (d) is a scatter-fit plot drawn after indentation of the baseline data. As can be seen from these four scatter plots, corporate carbon emissions along with green finance are negatively correlated. Thus, it may be inferred, at least in part, that green finance can assist enterprises in lowering their greenhouse gas density. Of course, further accurate measurement tests are needed to determine whether this conclusion is strictly statistically significant.

[Insert Fig. 4 here]

4. Empirical test

4.1 Fundamental regression

Table 2 displays the fundamental regression findings for this article. Regression is performed

for the main explicable variables and explained variables in column (1) without adding additional elements. At the 1% level, the calculated value is firmly negative, indicating that green finance can lower an enterprise's quantity of carbon. Control variables are added starting with column (2). The columns (3) - (6) begin to add the year, industry, province and individual fixed effect in turn. From the above regression results, the core conclusion expressed in the regression results remains unchanged. So green finance can help enterprises lower carbon output and achieve the goal of "dual carbon". Based on the theoretical analysis of this study, the potential reasons for this outcome may lie in the role of green finance at the provincial level in promoting industrial restructuring, enhancing green development, and fostering regional innovation, thereby providing crucial support for achieving the transition to a low-carbon economy. At the enterprise level, green finance not only reduces financing costs but also encourages firms to increase investment in environmental protection technologies, further reducing carbon emissions. Moreover, enhancing external regulatory oversight and standardizing the green finance market order will help ensure that funds are effectively utilized for green projects, thereby minimizing carbon emissions and achieving sustainable development goals to the fullest extent possible.

First, according to the control factor data from regression, there is a negative correlation between corporate dioxide emissions and the enterprise growth pace and enterprise status. The increase in the percentage of an enterprise's assets in general is used to express *Tagr.* Increased expansion in total assets means that more money may be allocated to enterprises to lower emissions, enterprises will also have a higher effect on lowering emissions. *nonindep* of enterprises shows that emission reduction level is better when the directors of enterprises concurrently serve as the management level. The regression coefficients of *govcon1_p*, ln*age* and *top10_HHI* have a notably bright outlook. It implies that the greater the degree of carbon dioxide released when the enterprise is managed by the government, the older the enterprise and the *top10_HHI*. In combination with the above, assume that state-owned holding, older and higher degree of equity concentration of enterprises, these enterprises have a high growth rate, and directors concurrently serve as management. The additional features unique to these enterprises and their willingness to minimize emissions afterwards determine the ultimate extent of carbon emissions of these enterprises. In addition, the correlation direction of the regression coefficients of ln*size*, *cflow, roa, EP*, *ED*, *ER* have all undergone sudden changes. However, the correlation direction of the regression

coefficient of the *lev* and *open* did not change, but the significance decreased. The possible cause of these changes is that this paper controls too much fixed effect and captures too much short-term fluctuation effect.

[Insert Table 2 here]

4.2 Endogeneity analysis

(1) Controlling joint effects. All the regressions in this paper are based on model formula (1), and the reliability of formula (1) depends on the endogenous magnitude of explanatory variables. There are multiple factors contributing to the endogeneity of primary explaining variables. Using the data that is available and the benchmark framework established in this research, there may be several cases of simultaneity of variables, two-way causality, and variable omission. The simultaneity of variables refers to the interdependence of multiple variables and their simultaneous determination. In general, if the core explanatory variable and the explained variable are simultaneous, then the explanatory variable must have endogeneity. The difference with the feedback of variables is that the simultaneity of variables is determined simultaneously. However, the feedback between variables is not necessarily, and the feedback will affect the next period but not necessarily the current period. Therefore, there must be endogeneity in the association between variables. Enterprises with lower carbon dioxide emissions are more inclined to engage in green finance, despite the fact that the green finance lowers their emission intensity. This is known as two-way causality. In this case, the core explanatory variable and the explained variable are causal to each other. In addition, the missing variable refers to the possibility that other factors affecting the enterprise's carbon emissions have not been controlled. This paper has controlled the relevant variables at the enterprise and provincial levels as much as possible. But in terms of rigor, it cannot guarantee that all the influencing factors are effectively controlled. In order to exclude the possibility of endogeneity caused by these factors, further joint control is performed on the baseline regression. As shown in Table 3, this paper gradually controls the industry-province, industry-individual, province-individual and year-industry effects on the basis of baseline regression. The findings in Table 4 demonstrate that the core conclusion has not changed.

[Insert Table 3 here]

(2) Instrumental variable regression. This paper has tried its best to control the enterprise-level variables and provincial-level variables related to explanatory variables. The above also carried out joint control of relevant level variables, but there is still the possibility of missing variables, resulting in endogeneity problems. To guarantee the correctness and impartiality of the estimation, and the rigor of the empirical findings, this research uses the instrumental variable for further testing. The selection of instrumental variables should not only be related to endogenous variables, but also satisfy exogenous conditions. Consequently, this research takes the provincial data as reference and selects the average of green finance data of other provinces as the instrumental variable. The level of economic development in each province is not consistent, and there are differences in policies. However, there is little variation in the state of development of green finance across different provinces as long as green financial goods remain unified in the national market. Consequently, the average amount of green finance outside of the provinces has a strong association with the principal explanatory variable, satisfying the correlation requirements for instrumental variables. Furthermore, the degree of green finance development in other provinces is closely related to their local financial and economic policies, and it falls under each province's economic category. Nonetheless, the province's extent to environmental enforcement and the organization's desire to control the environment have a link to the pollution intensity of the province's enterprises. But is not related to the economic category of other provinces, so it meets the exogenous conditions of instrumental variables. Table 4 summarizes the findings of the IV, where the in the first two columns control the fixed effects of year and province, year and industry, respectively. Column (3) is a synthesis of the first two columns, controlling for three fixed effects: year, province, and industry. In column (4), individual fixed effects are added on the basis of column (3). It is not difficult to see from the table that the results are significant. In addition, the Kleibergen-Paaprk Wald *F* values and the Kleibergen-Paaprk *LM* values pass the unrecognizable test respectively.

[Insert Table 4 here]

4.3 Robustness test

To mitigate potential confounding factors, this study also incorporates appropriate adjustments to the empirical samples. Firstly, since that the 2020 coronavirus outbreak's ramifications, there are large fluctuations in corporate data. Therefore, the sample data of 2020 is eliminated in this paper, and the subsamples after elimination are used for analysis. The results are significantly valid when the estimated coefficient is 1%. This can be viewed in Table 5's first column. Secondly, China's four major cities have obvious geographical and economic and political advantages, which may affect the empirical results. In consideration of robustness, sample data of four municipalities were deleted in this research, and the outcomes can be noticed in Table 5's column (2). Thirdly, this research regresses the benchmark regression by substituting the clustering standard error. It is changed into the enterprise-level and the four-fold level of enterprise, industry, year and province respectively. The outcomes in Table 5 demonstrate this. The consequences indicate that green finance obviously lowers the carbon output intensity, which remains unchanged. Fourth, in order to have no extremum in the sample data, both of the extremes of the values of the primary explanatory variable undergo 1% tailing processing. The findings, which can be observed in the fifth column of Table 5, demonstrate that the fundamental conclusions of this research remain valid. On the basis of the four robustness tests above, this paper adds the instrumental variable test, whose results correspond to columns (6) - (10) in Table 5. It is not difficult to see that the outcomes of the first stage are still significant after the robustness treatment. The IV passed the unrecognizable test.

[Insert Table 5 here]

5. Further analysis

5.1 Mechanism testing

As per the preceding theoretical review, this research selects several mechanism variables to inspect the influence path of green finance upon the CO_2 emission. The specific content includes macro and micro levels:

(1) Macroscopic level

First, the effect of Industrial structure upgrading (*indus_up*). The index is expressed as the result of each industry divided by GDP and calculated according to a certain weight. The regression

findings for the green finance upon the industrial framework upgrading index are listed in Table 6's column (1). The findings reveal that the outcome is significantly positive, implying that green finance can encourage the area in which the enterprises are situated to make improvements to their manufacturing infrastructure. According to the theoretical analysis, the upgrading of industrial framework can lower the carbon output intensity of enterprises. Therefore, hypothesis 1 verifies that green finance encourages the modernization of the local industrial framework, which lowers enterprise pollute emission.

Second, the effect of green development. The effectiveness and sustainability of the local economic and social growth are reflected in the degree of local sustainable growth. The green development stage (*Gee)* is represented in this research by the green economic effectiveness improvement index. The connotation of green economy efficiency index is to maximize the expected output and minimize the non-expected output under certain input. In this paper, material capital, labor capital and resource loss are chosen as inputs. Gross Domestic Product is taken as the expected output index. Additionally, it is assumed that industrial smoke outputs, industrial wastewater, and manufacturing sulfur dioxide outputs are unexpected results. Based on this, each Chinese province's environmental utility is determined using the super efficiency SBM model with undesired product (Abd et al., 2023). The second column of Table 6 lists the result, and the result is not significant. Therefore, hypothesis 2 cannot be verified, and the conclusion has not been proved. The possible reason is that the green development level index is related to many factors, and as a result the degree of regional green growth cannot be directly influenced by the application of green financing.

Third, the effect of provincial technological innovation. In this paper, the logarithm of each province's financial expenditure on science and technology is used as the technological innovation level index (*tech_in*) of the province, and the empirical test is done. The third column in Table 6 lists the outcome. This shows that innovations in science and technology are positively impacted by green finance in the province. A thorough mathematical examination demonstrates enterprises can be encouraged to cut emissions and pollution by raising the province's technical innovation degree. Therefore, hypothesis 3 is verified.

(2) microscopic level

First, the effect of financing cost. In this paper, debt financing cost is selected as the enterprise financing costing index (*Cost1*) for empirical test. The calculation method is the percentage of the enterprise's financial expenses to the total liabilities. The regression result of the green-finance index upon the enterprise financing cost index is mentioned in the fourth column of Table 6, and the result is negative. It shows that green finance can reduce the financing cost of enterprises. Comprehensive theoretical analysis shows that the reduction of enterprise financing costs can promote enterprises to reduce carbon emissions. Therefore, hypothesis 4 has been verified.

Second, the effect of technical innovation. This paper first divides the cost of research and development by the main business income, and then takes the logarithm of it. The result is used to display the innovation degree (ln*RDS*) of enterprises. The column (5) of Table 6 lists the regression result, and the result is positive. This shows that green financing can raise enterprises' capacities for innovation in technology. Comprehensive theoretical analysis shows that enterprise technological innovation can cut down carbon emission intensity. Therefore, hypothesis 5 is verified.

Third, the effect of external supervision. The agency cost decreases with increasing external oversight levels. Lower agency costs will encourage businesses to invest more in research, which will lower carbon emissions. This piece evaluates the agency cost of enterprises (*cost3*) employing the percentage of operational income to total assets. The column (6) of Table 6 lists the result of green-financing index on agency cost of the enterprise, and the result is negative. This shows that green finance can reduce agency costs and improve the external supervision level of enterprises. Comprehensive theoretical analysis shows that the improvement of external supervision can promote enterprises to reduce carbon emission intensity. Therefore, hypothesis 6 is verified.

[Insert Table 6 here]

5.2 Heterogeneity analysis

(1) Heterogeneity of industrial pollution degree. Considering that enterprises with different pollution levels have varying demands for green finance, the degree of introduction of green finance also differs. Consequently, the impact of green finance on enterprises with different pollution levels may vary. Therefore, this paper categorizes enterprises into two groups: heavily polluting industries

and non-heavily polluting industries for research purposes. This paper summarizes the code[2] of heavily polluted sectors through the comparison between the heavy polluted trades in the Classification of Environmental Protection and the revised "*Classification of National Economic Industries*" in 2019. If the industry is heavily polluted, *pollute1*=1, otherwise *pollute1*=0. In this paper, the interaction term between the index of heavily polluted enterprises and the index of green finance is included. And it is displayed in the first column in Table 7. The outcomes show that the regression of green finance index is negative, and the interaction is prominent positive. This reveals that, in comparison to industries with less pollution, the influence of green financing on enterprises in highly polluting industries that lower their carbon production is comparatively smaller. The potential reasons for this outcome may lie in the fact that heavily polluting enterprises typically face higher environmental pressures and cost challenges. Consequently, they are more inclined to seek financial support for environmental upgrades and technological advancements. Moreover, during their transition, green finance provides them with more flexible financing terms and broader technological support. Coupled with strengthened regulatory oversight, heavily polluting enterprises are further incentivized and empowered to implement emission reduction measures, thus more effectively reducing carbon emissions.

(2) Heterogeneity of resource-based industries. The type of pollutants emitted by enterprises vary depending on their industry attributes, particularly with resource-based enterprises tending to produce more pollutants. The introduction of green finance may thus have significantly different effects on pollution control in these industries. Therefore, this paper categorizes enterprises into two groups based on industry resource categories: resource-based and non-resource-based industries, for research purposes. The article makes connection to the manufacturing sector's industry code from the 2019 Classification of National Economic Industries. The value of *resour1* is set to 1 if the corporate in a resource-based trade; otherwise, it is set to 0. In this paper, the interaction terms of resource-based enterprises and green-financing indicators are used for regression. The outcomes are displayed in the second column of Table7. The outcome of green-financing index upon enterprise CO_2 emission is obviously negative, but the regression of interaction term is positive. This shows

[2] The industry codes matching the manufacturing industry screened in the industry classification provisions relating to listed corporate and the "National Economy Industry Classification" are as follows: Coal -C25; Metallurgy -C32; Mining -C31, C33; Chemicals -C26, C29; Pharmaceuticals -C27; Brewing -C15; paper -C22; textiles -C17, C18, C28; tanning -C19.

that compared with other non-resource-based industries, green finance has worse carbon emission reduction effect on enterprises in resource-based industries. The potential reasons for this outcome may lie in the fact that resource-based enterprises typically face higher carbon emission pressures. Green finance, offering low-cost financing and technological support, can more effectively drive these enterprises to implement environmental technology upgrades and carbon reduction measures. Additionally, due to the heightened attention from the public and government, resource-based enterprises have a more urgent need to address environmental issues. Therefore, they are more willing to accept and apply the support provided by green finance.

(3) Heterogeneity of capital-intensive industries. Due to variations in the financial resources of enterprises, those with higher financial levels tend to improve their technological capabilities more rapidly, possess better pollution treatment equipment, and exhibit stronger pollution reduction capabilities. For such enterprises, the introduction of green finance can catalyze their inherent pollution reduction capabilities, resulting in greater benefits. With this consideration, this paper categorizes enterprises into capital-intensive and labor-intensive enterprises for classification and analysis. Compared with labor-intensive enterprises, the production of products depends more on technology and equipment in capital-intensive enterprises. The development of technology and upgrading of equipment require substantial spending on R&D. But the production of labor-intensive enterprises mainly depends on the labor force. In theory, capital-intensive enterprises typically spend more on research and development than labor-intensive enterprises. Therefore, in capital-intensive enterprises, the emission reduction outcomes of green financing will be better. To prove the point, this research makes an empirical test. This paper divides the capital intensity and labor intensity according to the median factor intensity of enterprises. Factor intensity is the percentage of a corporate's capital input to its labor input. If the factor intensity is greater than this median, it is a capital-intensive corporate (*zibenmiji*=1), or else it is a no capital-intensive (*zibenmiji*=0). In this paper, the capital intensity index and the interaction between green finance index and capital intensity index are calculated in the standard model. Additionally, Table 7, and its column (3) displays the outcomes. Both the result and the interaction outcomes are significantly negative. This shows that green financing has a better carbon reduction effect on enterprises in capital-intensive industries than others. The potential reasons for this outcome may stem from the fact that capital-intensive enterprises typically utilize large amounts of energy in their production

processes, leading to higher carbon emissions. Green finance, by providing low-cost financing and technological support, can more effectively drive these enterprises to implement energy-saving and emission-reduction measures. In contrast, labor-intensive enterprises rely less on significant energy consumption in their production processes. Consequently, labor-intensive enterprises may have less room for improvement in terms of carbon emissions.

(4) Heterogeneity of marketization level. The introduction of green finance requires substantial support from both government and market forces. As marketization levels vary across different regions, there are discrepancies in the degree of acceptance of green finance. Regions with higher levels of marketization tend to exhibit greater momentum in promoting green finance. Consequently, enterprises in these regions are more likely to adopt green finance, leading to better overall emission reduction outcomes. Therefore, this paper categorizes enterprises into two groups based on regional marketization levels: those in regions with high marketization levels and those in regions with low marketization levels, for further investigation and discussion. Accompanied by market-oriented reform in China, the market system and market rules have been continuously improved. In China, market-oriented economy has become the main economic body. Different provinces have different economic development and different market-oriented processes, so the development of enterprises in different regions is also different. According to the marketization index indicators of each province in China during the sample period, if the marketization index of the province is greater than the average marketization index, market1=1; otherwise, market1=0. In this paper, the interaction between marketization index and green finance index is calculated. The fifth column of Table 7 displays the conclusions, which demonstrate that the interaction coefficient is strongly unfavorable. It's likely that green finance has more of an effect on an enterprise's ability to cut carbon emissions the more marketized the province in which it operates. The potential reasons for this outcome may stem from the fact that capital-intensive enterprises typically utilize large amounts of energy in their production processes, leading to higher carbon emissions. Green finance, by providing low-cost financing and technological support, can more effectively drive these enterprises to implement energy-saving and emission-reduction measures. In contrast, labor-intensive enterprises rely less on significant energy consumption in their production processes. Consequently, labor-intensive enterprises may have less room for improvement in terms of carbon emissions.

[Insert Table 7 here]

6 Conclusions and policy recommendations

6.1 Conclusions

Since the Industrial Revolution in 1750, various economic behaviors of humans caused the utilization of fossil fuels and other energy sources, making the global climate abnormal. Especially in recent years, climate change has become worse, which has aroused widespread concern of all mankind. In such a context, green finance has emerged as an urgently needed solution. By introducing green finance mechanisms, it can encourage enterprises, governments, and various sectors of society to engage in renewable energy more actively, energy conservation, emission reduction, clean production, and environmental governance, thereby reducing the adverse impacts on the environment. Based on this background, this research constructs a comprehensive target of explaining variables. It is also matched with the data of listed corporates to investigate the mechanism. This paper's research leads to the following primary conclusions: (1) Regardless of sample limitations or additional robustness tests, green finance is going to lower the overall carbon dioxide emissions. (2) On the macro level, green finance mainly lowers pollutant emission by encouraging the modernization of the industrial framework and the advancement in innovation of the province; At the micro level, three methods exist by which green finance decreases an enterprise's atmospheric carbon quantity: financing effect, innovation effect and external supervision effect.

6.2 Policy recommendations

The acceleration of industrialization tends to be accompanied by a boost in consumption of energy. Emissions of pollutants will directly rise with energy demand. With the further aggravation of pollution, more and more governments attach importance to reducing pollution and emission. To achieve the "dual carbon" goal, governments will actively formulate relevant policies to lower the carbon output of their region. In the economic market, enterprises, as the main body of production and development, are the key pollution control objects concerned by the government and society. To guide enterprises to actively reduce pollution and emission, green financial products came into being. The widespread application of green finance provides crucial financial support and policy assurance for addressing environmental pollution issues. By directing funds towards

environmental protection industries, incentivizing the development of innovative technologies, and promoting the efficient utilization of resources, it contributes to improving environmental quality, reducing pollution emissions, and achieving the goals of sustainable economic development and ecological civilization. However, achieving effective utilization of green finance requires joint efforts from governments, financial institutions, enterprises, and various sectors of society. Only through collaborative endeavors can the widespread application of green finance be realized, propelling the global environmental governance towards a healthier and more sustainable future (Zhang et al., 2024). Furthermore, in the Chinese market, implementing policies related to green finance also offers multiple advantages for enterprises in reducing carbon emissions. Firstly, the introduction of policies provides enterprises with more and cheaper green financing channels, thereby reducing the financial costs of implementing environmental projects. Secondly, policies incentivize enterprises to increase investment in clean production technologies and environmental protection equipment, thus driving technological innovation and industrial upgrading. Additionally, the mandatory nature and regulatory rigor of policies enhance enterprises' compliance with environmental regulations, prompting them to take more proactive emission reduction measures and improve environmental quality. Overall, the implementation of green finance policies contributes to raising environmental awareness among enterprises, reducing carbon emissions, and promoting sustainable development. The findings of the research are crucial for various industries trying to prevent pollution and how enterprises in different regions use green finance to reach "dual carbon". Through the conclusions drawn in this paper, this paper will put forward three recommendations from the perspectives of government, enterprises and industries:

First, the function of green financing in advancing the modernization of regional industrial structures, raising the degree of marketization and advancements in technology should be pushed by global governments. The upgrading of industrial framework will reduce the proportion of enterprises with excessive energy use and emissions. The total amount of pollution emitted would also be reduced. In regions with higher marketization levels, the financial market is more perfect, and the allocation of resources is more effective. As a result, green finance has a greater impact on lowering entities' carbon dioxide density. Through scale economy and agglomeration economy, the enhancement of regional advances in technology development will enhance the innovation degree of enterprises for decreasing emissions. The improvement of enterprise emission reduction

technology makes enterprise carbon emission intensity decrease. The above empirical analysis results also show that in areas with high industrial structure upgrading and technological innovation level, enterprises can achieve better results in reducing their emission through green finance. It is evident that the global government should always pay attention to the upgrading of the local industrial structure, the level of marketization, and the level of technological innovation. These indicators have important implications for local companies to reduce carbon intensity through green finance. Specifically, the government can catalyze the role of green finance in pollution reduction and emission reduction in the region by implementing stricter environmental regulations, establishing comprehensive environmental monitoring systems, focusing on green core technologies, and optimizing the structure of foreign investment (Liu et al., 2024; Xu & Lin, 2024).

Second, enterprises in various industries around the world should pay attention to reducing financing costs and agency costs and give play to their innovation advantages when using green financial products for financing. Cost reduction and technological innovation are both important channels for enterprises to reduce their carbon emissions through green finance. Therefore, after enterprises obtain green financial products and reduce financing costs, they should first use the surplus available funds for pollution prevention of enterprises. Enterprises can invest part of the funds in the human capital and equipment needed to reduce pollution and emissions. The other goes into R&D to reduce emissions. From the theoretical analysis in this paper, it can be inferred that as firms reduce their financing costs, they will have more surplus funds available. Under the supervision of green finance policies, firms can allocate a portion of these funds to the human capital and equipment needed for pollution reduction and emission control, while another portion can be invested in research and development funds required for emission reduction technologies. The state ought to center its efforts on enhancing green finance's capacity to cut costs and encourage innovation in enterprises' manufacturing processes, so as to help enterprises achieve emission reduction targets. Due to the possibility of information asymmetry, it is necessary to strengthen regulatory oversight of enterprises by regulatory authorities during the process of utilizing green finance for financing. Regular inspections of the flow of funds and emission reduction behaviors of enterprises through various channels are required. This approach can mitigate moral hazards resulting from information asymmetry, enabling enterprises to utilize green finance more smoothly for pollution reduction and emission control (Wang et al., 2024).

Third, capital-intensive industries around the world should increase their use of green financial products. Green financial products can help capital-intensive enterprises reduce carbon intensity more effectively. According to the heterogeneity analysis in this paper, enterprises in different industries have different carbon emission reduction effects when using green financial products. Capital-intensive industries are better able to use green finance to reduce carbon intensity. However, among enterprises in high-polluting industries and resource-based industries, the function of green-financing on reducing corporate carbon outputs is poor. Therefore, companies in different industries around the world should formulate policies that adapt to their own industries based on this industry heterogeneity.

6.3 Future expectations

This paper still has a few flaws. The article solely examines the mode of action of green-finance services upon enterprise emission levels from each province using the local green-finance index due to the paucity of research data. Future studies can start from the level of prefecture-level cities to explore the study direction of this article in prefecture-level cities. Furthermore, the carbon data in this article are computed indirectly due to the outputs intensity of an organization is not publicly available., and there are certain errors. In the future, more precise data will be computed to further enhance the updates in this paper, and the research topic of this paper is further discussed.

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Figure Captions

Fig. 1 Global CO2 emissions by country in 2020 (million).

Fig. 2 Theoretical framework of green finance to reduce corporate carbon emissions.

Fig. 3 Evolution of green finance development level.

Fig. 4 Correlation between green finance and carbon emission intensity of enterprises.

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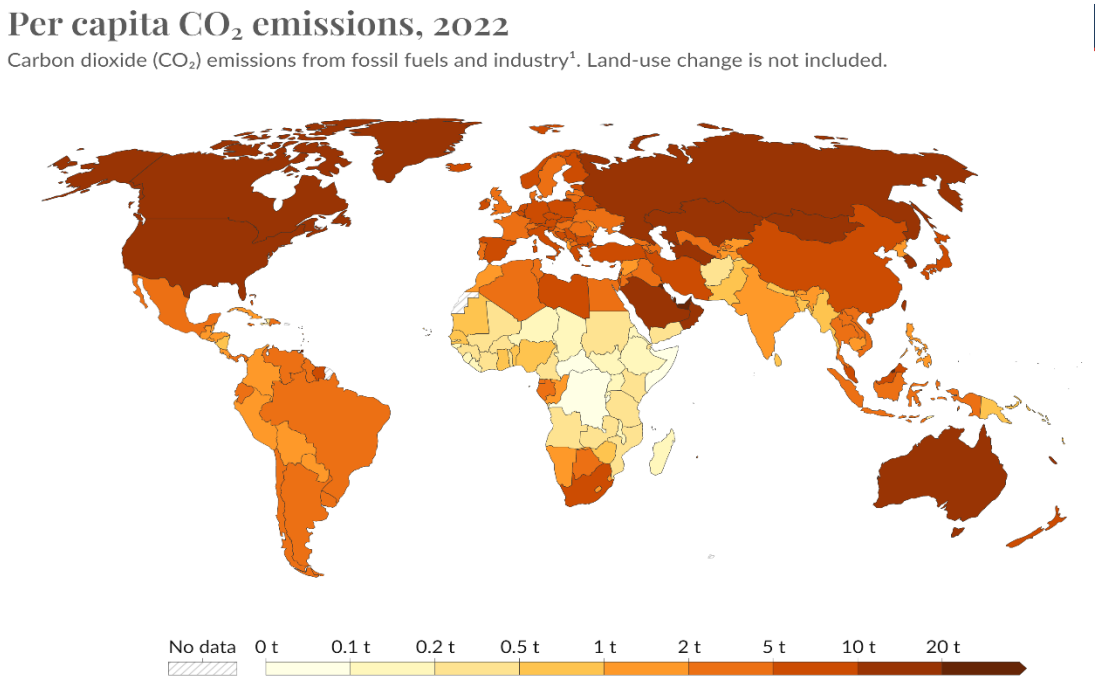

Fig. 1

Global CO2 emissions by country in 2020 (million).

Source: The World Bank https://ourworldindata.org/co2-emissions

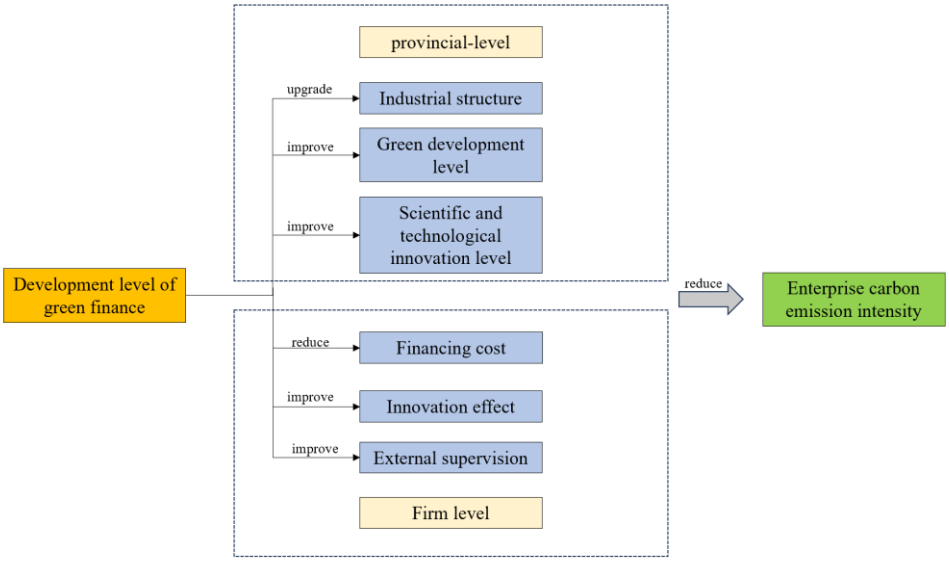

Fig. 2

Theoretical framework of green finance to reduce corporate carbon emissions

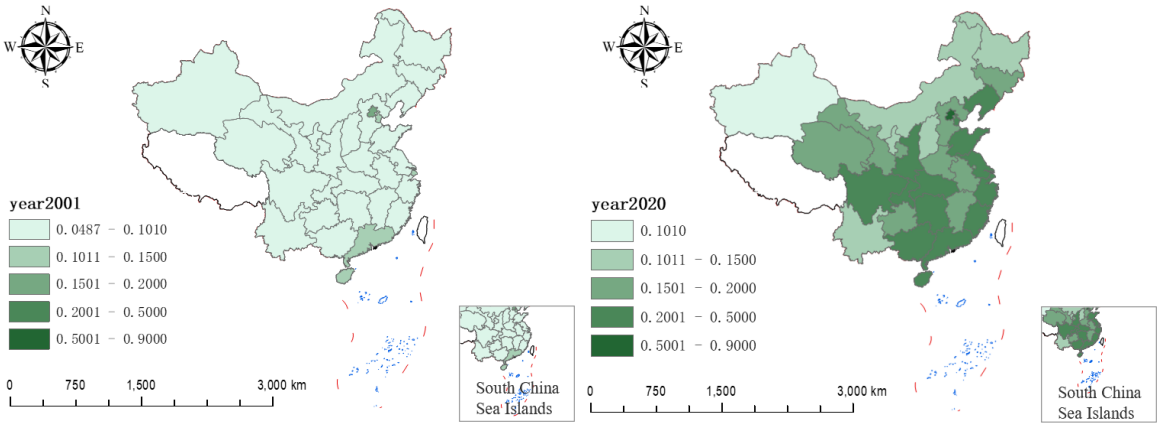

Fig. 3

Evolution of green finance development level

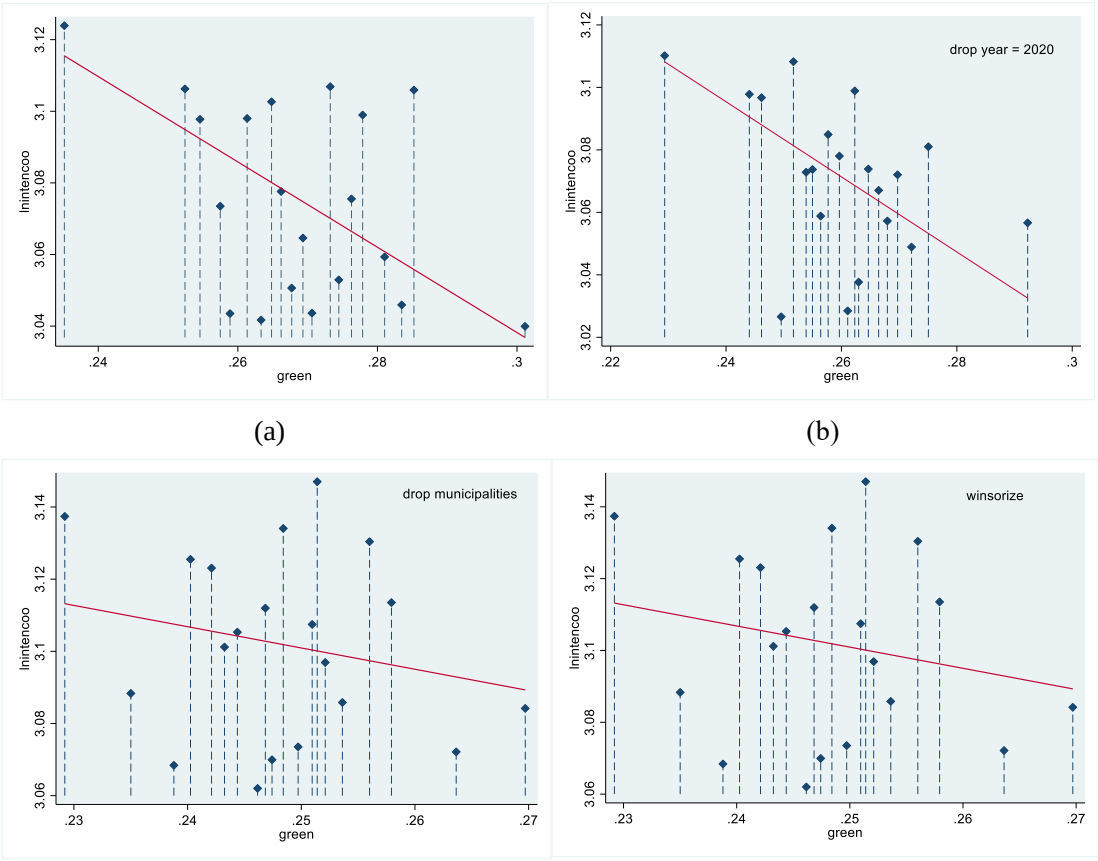

Fig. 4

Correlation between green finance and carbon emission intensity of enterprises

Table Captions

Table 1 Descriptive statistics of main variables.

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Table 1

Descriptive statistics of main variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
ln*intencoo*	16695	3.0755	1.1376	-4.5741	8.4717
green	16695	0.2687	0.1234	0.0713	0.8390
lnsize	16695	21.9427	1.1871	16.1613	27.5470
cflow	16695	0.0472	0.1172	-10.2162	2.2216
govcon1_p	16695	0.2710	0.4445	0.0000	1.0000
tagr	16695	0.2105	0.8157	-0.9725	45.4604
lnage	16695	1.9727	0.8978	0.0000	3.4340
top10_HHI	16695	0.4205	0.1905	0.1038	0.9849
lev	16695	0.4083	0.6157	-0.1947	63.9712
roa	16695	0.0380	0.9630	-48.3159	108.3657
nonindep	16695	0.3172	0.4654	0.0000	1.0000
open	16695	0.5409	0.3999	0.0087	1.8504
EP	16695	0.5246	0.2692	0.1873	2.1889
ED	16695	0.0423	0.0464	0.0004	0,2171
ER	16695	0.7779	0.6171	0.0000	2.5853

Table 2

Results of baseline regression.

	Univariate regression	Add control variable	Add year FE	Add industry FE	Add province FE	Add individual FE
	(1)	(2)	(3)	(4)	(5)	(6)
	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*
green	-1.7592***	-0.6961*	-0.7533***	-0.2105***	-0.6080***	-0.4000***
	(0.2672)	(0.4008)	(0.2384)	(0.0435)	(0.1914)	(0.1147)
lnsize		0.0579***	0.0582***	0.0109***	0.0105***	-0.0305***
		(0.0181)	(0.0178)	(0.0029)	(0.0029)	(0.0062)
cflow		0.1528	0.1050	-0.4973***	-0.5027***	-0.2168***
		(0.2292)	(0.1803)	(0.0845)	(0.0876)	(0.0445)
govcon1_p		0.1513***	0.1544***	0.0565***	0.0607***	0.0603***
		(0.0419)	(0.0386)	(0.0075)	(0.0073)	(0.0143)
tagr		-0.0492***	-0.0413***	-0.0161***	-0.0160***	-0.0054*
		(0.0177)	(0.0144)	(0.0056)	(0.0056)	(0.0028)
ln*age*		0.0979***	0.0951***	0.0556***	0.0579***	0.0463***
		(0.0216)	(0.0172)	(0.0040)	(0.0043)	(0.0097)
top10_HHI		0.2074***	0.2114***	0.0551***	0.0498***	0.0437***
		(0.0743)	(0.0609)	(0.0095)	(0.0090)	(0.0167)
lev		0.0780***	0.0724***	-0.0004	0.0006	0.0016
		(0.0259)	(0.0237)	(0.0177)	(0.0170)	(0.0057)
roa		0.0216	0.0164	-0.0417***	-0.0421***	-0.0103**
		(0.0218)	(0.0183)	(0.0086)	(0.0088)	(0.0044)
nonindep		-0.0324**	-0.0344**	-0.0189***	-0.0184***	-0.0061
		(0.0146)	(0.0139)	(0.0041)	(0.0040)	(0.0056)
open		-0.2979	-0.3137***	0.0514***	-0.0161	-0.0101
		(0.1827)	(0.0763)	(0.0143)	(0.0411)	(0.0246)
EP		0.3974***	0.3931***	-0.0534***	-0.0064	-0.0033
		(0.1027)	(0.0658)	(0.0136)	(0.0589)	(0.0330)
ED		1.8216**	1.9689***	-0.1481**	0.4999	-0.0578
		(0.7107)	(0.4286)	(0.0609)	(1.0135)	(0.5828)
ER		0.0935*	0.1013***	0.0182***	-0.0018	-0.0016
		(0.0542)	(0.0266)	(0.0029)	(0.0144)	(0.0093)
Constant	3.5482***	1.4549***	1.4687***	2.7709***	2.8837***	3.7516***
	(0.1322)	(0.4227)	(0.4275)	(0.0576)	(0.1038)	(0.1411)
year FE	NO	NO	YES	YES	YES	YES
industry FE	NO	NO	NO	YES	YES	YES
province FE	NO	NO	NO	NO	YES	YES
individual FE	NO	NO	NO	NO	NO	YES
Observations	16,695	16,695	16,695	16,695	16,695	16,560
R^2	0.0364	0.0886	0.0941	0.9422	0.9432	0.9840

Note: ***, **, and * indicate that the estimated coefficients are significant at the 1%, 5%, and 10% confidence levels,

respectively, and the robust standard error for clustering coefficients to the province-individual level is in parentheses. Unless otherwise specified, the following table is the same.

Table 3

Regression results after controlling for combined effects.

	Add industry × province FE	Add industry ×individual FE	Add province ×individual FE	Add industry × year FE
	lnintencoo	*lnintencoo*	*lnintencoo*	*lnintencoo*
	(1)	(2)	(3)	(4)
green	-0.4454***	-0.4380***	-0.4369***	-0.2037**
	(0.1176)	(0.1171)	(0.1173)	(0.0951)
Controls	*YES*	*YES*	*YES*	*YES*
year FE	*YES*	*YES*	*YES*	*YES*
industry FE	*YES*	*YES*	*YES*	*YES*
province FE	*YES*	*YES*	*YES*	*YES*
individual FE	*YES*	*YES*	*YES*	*YES*
Observations	16,555	16,511	16,496	16,492
R^2	0.9844	0.9845	0.9845	0.9904

Note: Limited to the layout, the situation of control variables is not reported here, which is basically consistent with Table 2. Unless otherwise specified, the following tables are the same.

Table 4

Regression results of instrumental variables with fixed effects added.

	year+province FE	industry+year FE	year+province +industry FE	year+province+industry + individual FE
	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*
	(1)	(2)	(3)	(4)
green	-0.7505*	-0.1988**	-0.5818***	-0.3663**
	(0.4155)	(0.0720)	(0.1855)	(0.1426)
First stage regression				
IV	-27.7164***	-27.6572***	-27.7157***	-27.7271***
	(0.3279)	(0.3826)	(0.3283)	(0.3892)
F	7145.73***	5224.34***	7127.94***	5075.98***
Kleibergen-Paap rk LM statistic	11.13***	9.07***	11.12***	11.16***
Kleibergen-Paap Wald F statistic	7145.73***	5224.34***	7127.94***	5075.98***
Cragg-Donald Wald F	2.2e+05***	2.9e+05***	2.2e+05***	1.9e+05***
year FE	YES	YES	YES	YES
industry FE	NO	YES	YES	YES
province FE	YES	NO	YES	YES
individual FE	NO	NO	NO	YES
N	16695	16695	16659	16659

Table 5

Robustness analysis and regression results of instrumental variables.

	Drop if year=2020	Eliminate Municipalities	Adjust the standard deviation clusters		Winsorization
	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo_w*
	(1)	(2)	(3)	(4)	(5)
OLS regression					
green	-0.3330***	-0.4759**	-0.3330**	-0.3330***	
	(0.1233)	(0.2058)	(0.1591)	(0.0711)	
green_w					-0.2789***
					(0.0997)
yearFE	*YES*	*YES*	*YES*	*YES*	*YES*
industry FE	*YES*	*YES*	*YES*	*YES*	*YES*
province FE	*YES*	*YES*	*YES*	*YES*	*YES*
individual FE	*YES*	*YES*	*YES*	*YES*	*YES*
N	14472	12462	14472	14472	14623
R^2	0.9844	0.9853	0.9844	0.9844	0.9876
IV regression					
	Drop if year=2020	Eliminate Municipalities	Adjust the standard deviation clusters		Winsorization
	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo_w*
	(6)	(7)	(8)	(9)	(10)
green	-0.2894**	-0.3066***	-0.2894*	-0.2894**	
	(0.1028)	(0.0670)	(0.1630)	(0.1236)	
green_w					-0.3387**
					(0.0958)
First stage regresssion					
IV	-27.8187***	-25.7493***	-27.8187***	-27.8187***	-26.2943***
	(0.4589)	(0.9299)	(0.1729)	(0.3326)	(1.4843)
F	3674.72***	966.79***	25878.60***	6995.47***	313.83***
Kleibergen-Paaprk LM statistic	4.33**	5.23**	296.67***	10.96***	4.46**
Kleibergen-Paaprk Wald F statistic	3674.72***	966.79***	2.6e+04***	6995.47***	313.83***
Cragg-Donald Wald F	1.9e+05***	6.3e+04***	2.3e+05***	2.3e+05***	1.2e+05***
year FE	*YES*	*YES*	*YES*	*YES*	*YES*
industry FE	*YES*	*YES*	*YES*	*YES*	*YES*
province FE	*YES*	*YES*	*YES*	*YES*	*YES*
individual FE	*YES*	*YES*	*YES*	*YES*	*YES*
N	14472	12462	14472	14472	14472

Table 6

Results of mechanism test.

	Provincial level			Enterprise level		
	(1)	(2)	(3)	(4)	(5)	(6)
	indus_up	*Gee*	*tech_in*	*Cost1*	ln*RDS*	*cost3*
green	0.4000***	0.2644	1.5670**	-0.0300*	0.3269*	-0.3391**
	(0.0916)	(0.2482)	(0.6525)	(0.0167)	(0.1915)	(0.1386)
indus	0.1147	0.7573**	-2.1045***	-	-	-
	(0.1326)	(0.3264)	(0.5787)			
consume	0.1598**	-0.1937	1.6895***	-	-	-
	(0.0671)	(0.1334)	(0.3423)			
trans2	0.0487*	0.1370**	0.1783	-	-	-
	(0.0278)	(0.0589)	(0.1577)			
gover	-0.4847**	0.4282*	-1.7892***	-	-	-
	(0.1932)	(0.2269)	(0.5590)			
infor	-0.0083	0.5464**	0.2511	-	-	-
	(0.1373)	(0.2767)	(0.6765)			
Controls	NO	NO	NO	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES
industry FE	NO	NO	NO	YES	YES	YES
province FE	YES	YES	YES	YES	YES	YES
individual FE	NO	NO	NO	YES	YES	YES
Constant	1.3251***	-1.2918*	11.6448***	0.0530*	1.8654***	2.1854***
	(0.3370)	(0.7422)	(1.9068)	(0.0287)	(0.2926)	(0.3712)
Observations	270	270	267	8,121	13,765	8,368
R^2	0.9594	0.9566	0.9670	0.6459	0.8605	0.8451

Table 7

Results of heterogeneity test.

	heavy polluting enterprise	resource-based enterprise	capital intensive enterprise	marketization index
	(1)	(2)	(3)	(5)
	ln*intencoo*	ln*intencoo*	ln*intencoo*	ln*intencoo*
green	-0.5675***	-0.4809***	-0.3578***	0.2781
	(0.1521)	(0.1348)	(0.1174)	(0.3310)
green×pollute1	0.7784**			
	(0.3096)			
green×resour1		0.8271**		
		(0.4015)		
green×zibenmiji			-0.0872**	
			(0.0385)	
zibenmiji			0.0258*	
			(0.0141)	
green×market1				-0.6394**
				(0.3090)
market1				0.0933**
				(0.0447)
Controls	YES	YES	YES	YES
year FE	YES	YES	YES	YES
industry FE	YES	YES	YES	YES
province FE	YES	YES	YES	YES
individual FE	YES	YES	YES	YES
Constant	3.6780***	3.7153***	3.7461***	3.5607***
	(0.1429)	(0.1415)	(0.1418)	(0.1505)
Observations	16,560	16,560	16,560	19,496
R^2	0.9841	0.9841	0.9840	0.9856