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Research article

The mechanism of green finance's impact on enterprises' sustainable green innovation

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Abstract: Global attention toward environmental sustainability and economic green transformation is on the rise. Green technology innovation plays a crucial role in achieving green economic development, making the study of enterprises' sustainable green innovation highly valuable. This paper aims to examine the influence mechanism of green finance on enterprises' sustainable green innovation. To achieve this, panel data from A-share-listed enterprises in Shanghai and Shenzhen between 2012 and 2020 are utilized as the basis for analysis. The results show that: (1) Green finance plays an important role in encouraging enterprises' sustainable green innovation. (2) The test of the intermediary effect reveals that green finance can stimulate enterprises' sustainable green innovation by increasing continued R&D investment. (3) The moderating mechanism test reveals that enterprise financing restrictions and enterprise debt default risk moderate the influence of green finance on enterprises' sustainable green innovation. Furthermore, for enterprises with high financial constraints and a high risk of debt default, the development of green finance is particularly important in fostering their long-term green innovation. (4) The study concludes that all four types of sustainable green innovation, namely, strategic, substantive, independent and cooperative, exhibit the promotion effect of green financial development, the intermediary effect of continuous R&D investment and the moderating effect of financing constraints. Enterprises with a higher risk of defaulting on their debt are more likely to make significant, independent and sustainable green innovations.

Keywords: green finance; enterprises' sustainable green innovation; continuous R&D investment; financing constraints; debt default risk

JEL Codes: C23, G18, G32, O31

1. Introduction

The survival and advancement of humanity have been significantly impacted recently by the decline of the ecological environment. Enterprises play a critical role as the main actors in this process, serving as a crucial driver in encouraging the sustainable development of the global economy through green innovation. Under the consideration of social responsibility and sustainable development, enterprises aspire to achieve continuous growth and development through green innovation. However, innovative activities often require significant initial cost investments. These costs include establishing research infrastructure and hiring qualified R&D personnel. It is crucial to remember that once the choice is made to start the innovation process, there may be significant opportunity costs involved in stopping (Manez et al., 2009). According to relevant research, continuous innovation may not bring good economic benefits (Demirel et al., 2012; Guarascio et al., 2019; Bianchini et al., 2019). Some studies have also shown that there may be a certain threshold for innovation factors to generate green economic benefits (Wang et al., 2023). This means that enterprises face the characteristics of high sunk costs, irreversibility, long R&D cycles, highly uncertain output and low returns in carrying out sustainable green innovation. Consequently, companies often confront the dual pressure of significant adjustment costs and financing expenses for their R&D investments. Financing restrictions affect both enterprises' decisions about innovation and the results of those efforts, according to research by Garcia-Quevedo et al. (2018). This finding is consistent with the studies conducted by Andersen (2017) and Yu et al. (2021), which suggest that high financing constraints can hinder enterprises' investments in green technologies, consequently weakening their green innovation capabilities. Indeed, since the Paris Agreement was reached in 2015, there has been a growing focus on green finance (hereinafter referred to as GF) from governments, scholars and enterprises (Tolliver et al., 2021). GF represents a distinctive institutional framework for investment and financing, aiming to regulate the financial flows across public, private and non-profit sectors, including banking, microfinance, insurance and investment (Ahmad et al., 2022). By employing market mechanisms to reallocate economic resources, GF can effectively steer capital and resources toward industries that promote resource-saving and environmentally friendly practices. By doing this, it can enable enterprises that are actively involved in green innovation to overcome their capital restrictions (Yu et al., 2021).

In the realm of research on GF and green innovation, some studies have explored the topic through the lens of GF policies and instruments (Yu et al., 2021; Zhang et al., 2022; He et al., 2022). Traditionally, these studies have often employed a single indicator to measure the effectiveness of green financial instruments and policies. However, some scholars have argued that policy pilots like green credit and green bonds only represent a portion of the broader concept of GF, and it is challenging to capture the comprehensive development of GF using a single indicator alone (He et al., 2022; Debrah et al., 2022; Lee et al., 2022). Therefore, to gain a deeper understanding of the relationship between GF and its impact on enterprise innovation, a comprehensive evaluation of the macro-level development of GF has become a crucial aspect of research (Debrah et al., 2022; Lee et al., 2022). In recent years, there has been a growing body of literature focusing on the comprehensive assessment of macro GF development and its influence on the green innovation of micro-enterprises (Ye et al., 2021; Jiang et al., 2022; Li et al., 2022). It is true that existing research primarily focuses on the short-term effects of GF development on green technology innovation or enterprise green innovation, while paying relatively less attention to the long-term

sustainability value of enterprise green innovation (Geroski et al., 1997; Bianchini et al., 2019; Antonioli et al., 2021). As a result, not enough attention has been given to the effects of green finance development on firms' sustainable green innovation.

Given the limited number of studies on the comprehensive evaluation of the development level of GF in the existing literature, the majority of attention on corporate green innovation is primarily directed toward short-term innovation output. However, there is insufficient sustained attention given to the ongoing corporate green innovation output (Le Bas, 2015; Guarascio and Tamagni, 2019). Furthermore, existing research rarely establishes a connection between the comprehensive evaluation system of the development level of macro GF and the impact of continuous green innovation in micro-enterprises. Additionally, the analysis of the mechanisms through which the GF level affects the sustainable green innovation of firms needs to be further enhanced. Therefore, undertaking a thorough examination of the mechanisms that influence the growth of GF and the sustainable green innovation of firms has enormous theoretical value and practical significance.

In this study, the relationship between GF development and sustainable green innovation at the enterprise level is especially examined using China as a case study. We use panel data at the micro- and provincial level for A-share listed enterprises in Shanghai and Shenzhen from 2012 to 2020 to conduct this research. The fixed effect model is used to examine how GF development affects enterprises' commitment to sustainable green innovation. We also examine the moderating effects of enterprise debt default risk and enterprise financing risk on the aforementioned impact, as well as the intermediary effect of continuous R&D expenditure.

This study aims to make several contributions. First, it provides a systematic measurement of the level of GF at the macro level, using a multi-dimensional index system. This contributes to enhancing the overall understanding of macro GF development across various sectors of society. Second, from a long-term sustainability perspective, the study examines the impact of GF on corporate green innovation. Additionally, the paper incorporates the development of GF, continuous R&D investment by enterprises, as well as debt default risk and financing risk into an analytical framework for studying continuous green innovation. The study conducts in-depth and detailed analysis to explore the theoretical mechanisms underlying these factors. By establishing a theoretical analysis framework, this study contributes to a better understanding of the theoretical relationship between GF development and enterprise's sustainable green innovation. Additionally, the empirical testing conducted in this paper, using China as an example, examines the impact mechanism and heterogeneity characteristics of macro GF on micro enterprises' sustainable green innovation. This research conducted in a specifically adapted Chinese context helps to uncover and understand the practical characteristics of GF and continuous green innovation in emerging markets. The study provides valuable empirical evidence and policy implications, not only for China but also for other emerging market countries, in building a macro green financial system and promoting continuous green innovation among micro-enterprises.

2. Theoretical analysis and research hypotheses

2.1. GF and enterprises sustainable green innovation

Enterprise green innovation is pivotal in enhancing competitiveness, cost reduction and brand image enhancement (Zameer et al., 2019). While partial or sporadic green innovation, such as green process innovation or green product innovation, may yield short-term benefits, it lacks long-term

strategic significance (Xie et al., 2019). It is only through continuous green innovation that enterprises can achieve sustainable development and foster the coordinated development of environmental resources. However, according to the resource dependence theory, enterprises have limited resources, so achieving sustainable green innovation requires rational allocation of limited resources. At the same time, green innovation is characterized by sunkness, irreversibility, long R&D cycle, highly uncertain output and low returns. If enterprises want to continuously promote green innovation and enhance their competitiveness, they must obtain a large amount of external finance to support green innovation activities. Therefore, GF is becoming an essential tool for fostering the greening of the economy and supporting green innovation inside enterprises (Desalegn, 2022). By utilizing GF, enterprises can access funding support specifically tailored for projects with environmental protection characteristics. This not only broadens the financing avenues available to enterprises but also helps optimize their investment and financing practices. Moreover, GF enhances enterprises' confidence and expectations regarding the direction of environmental regulatory policies (Yu et al., 2021). The support of GF facilitates enterprises in acquiring larger-scale, longer-term and lower-cost external funding. This, in turn, strengthens enterprises' commitment to long-term green technology R&D and encourages a sustained focus on green innovation activities. Moreover, GF serves as a mechanism for resource allocation, incentives and constraints. It provides external motivation for enterprises, thereby promoting ongoing green innovation endeavors.

Hypothesis 1: GF has a favorable effect on enterprises' sustainable green innovation.

2.2. Intermediary effect of enterprises' continuous R&D investment

Achieving a breakthrough from quantitative change to qualitative change in green technology necessitates the continuous accumulation of knowledge and relevant technology. Continuous investment in research and development (R&D) serves as the fundamental guarantee for this process. Research indicates that the dynamic increase in green innovation returns and the high sunk costs associated with green innovation incentivize enterprises to invest continuously in R&D and adopt sustainable green innovation strategies (Peters, 2009). In other words, while the sunk costs resulting from early R&D investment may impede the exit from green innovation, they also motivate enterprises to persist in R&D investment to attain sustainable green innovation (Peters, 2009; Yu et al., 2022). Continuing R&D investment enables enterprises to accumulate knowledge and technological capabilities, enhancing their internal innovation capacities. This, in turn, supports enterprises in achieving higher levels of green innovation output and sustainable green innovation. On one hand, such practices contribute to market differentiation and enable enterprises to attain a leading position. On the other hand, they also strengthen resilience to risks and enhance industry competitiveness.

GF serves as a crucial external financing channel for enterprises, with its resource allocation function addressing the issue of insufficient investment in green innovation R&D. It helps reduce R&D costs for enterprises and enhances their willingness to allocate funds to R&D (Cui and Peng, 2023). Additionally, GF necessitates a more rigorous environmental information disclosure system. This, on the one hand, reduces the displacement of green innovation funds from production and sales activities, encouraging enterprises to utilize the funds for innovation. On the other hand, investors can make more accurate valuation decisions based on enterprises' environmental performance. This enhances enterprises' motivation to invest in continuous R&D and improves their environmental competitiveness (Hong et al., 2020; Ding et al., 2022). Moreover, with the support of GF, the

accumulation of human capital and technical knowledge increases alongside continuous R&D investment. The knowledge updates and technological advancements resulting from green R&D investment provide endogenous support for enterprises' ongoing innovation output.

Hypothesis 2: GF promotes continuous R&D investments, thereby facilitating enterprises' sustainable green innovation.

2.3. Moderating effect of financing constraints and debt default risk

The core concept of GF entails allocating credit based on environmental constraints. This approach aims to direct capital toward green enterprises, thereby enabling a greater inflow of funding for environmentally friendly projects (Jin et al., 2022). Through the implementation of supportive policies and incentives, financial institutions can offer loans to companies that prioritize environmental governance at lower interest rates. This helps enhance the maturity profile of corporate debt financing and reduces overall financing expenses for such enterprises (Mirza et al., 2023). Furthermore, the advancement of GF exerts pressure on heavily polluting enterprises to transition toward more sustainable practices. Enterprises with high pollution levels may experience increased costs when obtaining GF credit. This, in turn, reduces their debt repayment capacity and ability to bear risks, potentially amplifying operational and financial risks (He et al., 2022). In light of risk factors, external investors may elevate the cost of capital usage or opt to refrain from investing in such enterprises, further adding to the financing expenses incurred by heavily polluting companies.

By utilizing the capital allocation mechanism of environmental information, GF amplifies the investment risk faced by polluting enterprises. This, in turn, reduces their access to financing opportunities while channeling green funds toward industries or enterprises that adhere to green credit rating standards and engage in long-term clean production (Shen and Liao, 2020). Given that financing constraints significantly impact an enterprise's economic decision-making, GF can play a crucial role in regulating actions such as ongoing green innovation. In other words, the level of financing constraints an enterprise faces greatly influences its motivation and willingness to undertake sustained green innovation.

Hypothesis 3: GF can partially alleviate the issue of high financing constraints and facilitate the promotion of the enterprise's sustainable green innovation.

Currently, enterprises are encountering mounting pressure and increasing cash flow issues amid economic transformations and uncertain development environments. These challenges heighten the risk of debt defaults. The consequences of corporate debt default extend beyond employee losses and disruptions in the supply chain. They also pose significant obstacles to the green transformation efforts of enterprises. When confronted with the risk of debt default, enterprise management, driven by concerns over their position and external pressures, often tends to steer clear of risks. Instead, they favor stable projects that can optimize short-term performance, while shelving long-term and innovative endeavors (Wang et al., 2023). Consequently, the ability of enterprises to sustain green innovation is adversely affected when they face the risk of debt default.

The environmental information disclosure system implemented in GF contributes to enhancing investor confidence in corporate financial and non-financial information to a certain degree. As a result, it helps mitigate adverse selection issues between creditors and debtors (Yadav et al., 2016). This improved credibility of information leads to increased investor confidence, subsequently reducing the cost of corporate debt financing. It also alleviates the financial burden on enterprises and elicits a positive

response from the capital market. These measures, to some extent, contribute to boosting the cash flow of enterprises and reducing the risk of corporate debt default (Yadav et al., 2016; Du et al., 2017).

In a context where the risk of debt default is significantly reduced and market guidance is provided, the promotion of continuous green innovation among enterprises is greatly facilitated. Taking into account the significant impact of debt default risk on the decision-making behavior of corporate managers and investors, it is likely that debt default risk plays an important role in regulating the economic decisions of GF regarding enterprises' sustainable green innovation. In other words, the influence of GF on enterprises' motivation and willingness to engage in continuous green innovation is largely influenced by the level of debt default risk they face. When debt default risk is lowered, enterprises become more inclined and motivated to pursue sustained green innovation.

Hypothesis 4: GF can partially alleviate the problem of high debt default risk and promote enterprises' sustainable green innovation.

See Figure 1 for the framework diagram of specific theoretical analysis.

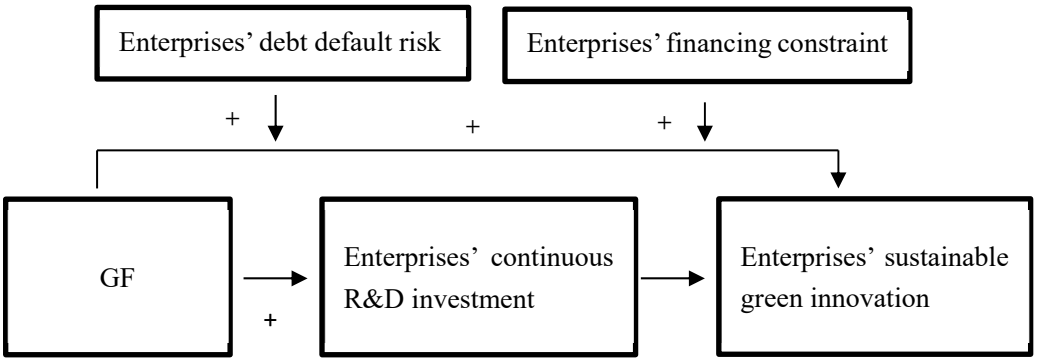

Figure 1. Theoretical analysis framework diagram.

3. Model, variables and data description

3.1. Model

3.1.1. Benchmark model construction

The fixed effect model is advantageous in controlling for individual characteristics and time series, relaxing the assumption of serial independence, capturing the effect of individual variation and time covariation and processing the characteristics of panel data. These advantages can all contribute to improving the precision and accuracy of analysis results. Therefore, this paper employs the fixed effect model to empirically test the impact of GF on enterprises' sustainable green innovation, building upon previous theoretical analysis. To do so, the following benchmark model has been constructed:

$$SGI_{it} = a_1 + a_2 GF_{it} + a_3 x_{it} + \delta_h + \lambda_y + \gamma_u + \varepsilon_{it}. \quad (1)$$

The subscript i in the equation represents different entities or individuals, while t represents different years. SGI is the dependent variable in this study, representing enterprises' sustainable green innovation (SGI). GF is the key explanatory variable, representing green finance. x_{it} represents the

set of control variables, with detailed control variables and their measurement methods described later in the text. δ_h denotes individual fixed effects, λ_y represents time effects, γ_u represents industry effects and ε_{it} represents the random error term.

3.1.2. Intermediary effect model

Building on the theoretical analysis outlined earlier, this study seeks to delve deeper into the intermediary role of continuous R&D investment in the link between GF and enterprises' sustainable green innovation. To this end, the study constructs a mediation model as follows:

$$CRDI_{it} = a_1 + a_2 GF_{it} + a_3 x_{it} + \delta_h + \lambda_y + \gamma_u + \varepsilon_{it},$$
$$SGI_{it} = a_1 + a_2 GF_{it} + a_3 CRDI_{it} + a_4 x_{it} + \delta_h + \lambda_y + \gamma_u + \varepsilon_{it}. \quad (2)$$

The variable CRDI in the equation serves as the intermediary variable in this study, representing enterprises' continuous R&D investment (CRDI).

3.1.3. Moderating effect model

Furthermore, incorporating the theoretical framework analysis and referring to the model setting method of Wang et al. (2023b), this study extends equation (1) by including moderation variables of financial constraints and debt default risk, as well as interaction terms between GF and both financial constraints and debt financing risk. As a result, the moderation effect models represented by equations (3) and (4) are obtained, aiming to further examine the moderating role of GF in the relationship between enterprises' sustainable green innovation.

$$SGI_{it} = a_1 + a_2 GF_{it} + a_3 FC_{it} + a_4 GF_{it} \times FC_{it} + a_5 x_{it} + \delta_{\not h} + \lambda_y + \gamma_u + \varepsilon_{it}, \quad (3)$$

$$SGI_{it} = a_1 + a_2 GF_{it} + a_3 DDR_{it} + a_4 GF_{it} \times DDR_{it} + a_5 x_{it} + \delta_h + \lambda_y + \gamma_u + \varepsilon_{it}. \quad (4)$$

In the formula, FC_{it} is the moderating variable of financing constraints, and DDR_{it} is the moderating variable of debt default risk.

3.2. Variable description

3.2.1. Explained variable

In this study, the dependent variable is the SGI. Following the research methods of He et al. (2017), this study utilizes a before-after comparison of the green innovation output index (OIN) to measure the enterprises' sustainable green innovation. This is the dependent variable of the study, representing corporate green continuous innovation. The calculation formula is detailed below:

$$SGI_t = \frac{OIN_t + OIN_{t-1}}{OIN_{t-1} + OIN_{t-2}} \times (OIN_t + OIN_{t-1}) \quad (5)$$

3.2.2. Core explanatory variables

In this study, green finance (GF) is the key explanatory variable. Taking a cue from Lee and Lee's (2022) research, we adopt a comprehensive approach to measure GF by considering its four key dimensions: green credit, green securities, green insurance and green investments. We select appropriate indicators corresponding to each dimension to construct a composite index of GF. The comprehensive evaluation framework for the GF index, including the measurement methods for relevant indicators and their respective weights, is presented in Table 1.

Table 1. Comprehensive indicator system of development level.

Tier 1 indicators	Tier 2 indicators	Definition of indicators	Indicator direction
Green Credit	Interest ratio of high energy-consuming industries	High energy-consuming industrial interest/industrial interest	-
Green Securities	The proportion of the market value of high energy-consuming industries	Value of six high energy-consuming A-shares/total market value of A-shares	-
Green Investment	The proportion of investment in environmental pollution	Investment in pollution control /GDP	+
Green Insurance	Agricultural insurance scale ratio	Agricultural insurance income/total agricultural output value	+
Carbon Finance	Carbon intensity	Carbon dioxide emissions/GDP	-

The calculation of the composite index of GF involves three steps. In the first step, we apply mathematical transformations to standardize each signal indicator to address measurement issues and enhance comparability and coherence among the indicators. To do this, we classify the indications as either positive or negative, then choose the standardization approach that best fits the indicator's characteristics. The specific calculation process for standardization is shown in equations (6) and (7). In the second step, after standardization of the indicators, we compute the weights for each indicator individually. According to each indicator's relative significance during the evaluation process, weights are assigned to them using the weight matrix (W_j). Finally, in the third step, we calculate the composite index of GF by combining the standardized values of the indicators with their respective weights using equation (8).

$$\text{Positive indicator: } X_{ij}^{s+} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}, \tag{6}$$

$$\text{Negative indicator: } X_{ij}^{s-} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}, \tag{7}$$

$$GF_i = \sum_{j=1}^{J} W_j \times X_{ij}^{s}. \tag{8}$$

To offer a lucid and straightforward understanding of the spatiotemporal evolution of GF in different provinces of China, we present kernel density plots of GF levels in 2012 and 2019 in Figure 2. The corresponding figures illustrate the following observations: compared to 2012, the kernel density of 2019 shows a leftward shift in the center, a decrease in kurtosis and an elongation of the tail. The kernel density curve features of the changes in GF indicate an overall decline in the level of GF in China, accompanied by an increasing regional disparity trend.

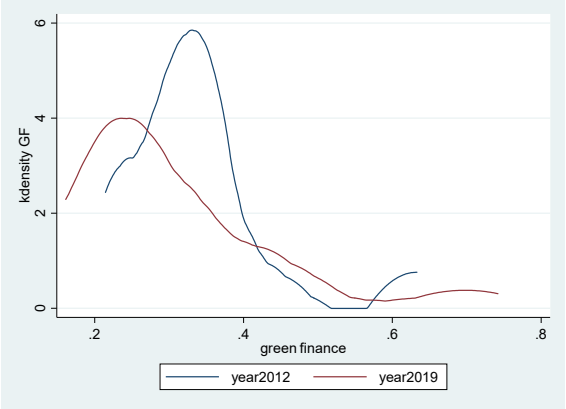

Figure 2. Kernel densities for 2012 and 2019.

Note: To reduce the impact of the epidemic in 2020 on green finance and objectively reflect the development of green finance, this study selects 2019 as the final presentation year of green finance.

3.2.3. Control variables

The following control variables are chosen for this investigation by consulting the current literature: enterprise size (Size) is measured by the logarithm of the enterprises' total assets. Asset-liability ratio (Alr) is measured by the ratio of total liabilities to total assets. Management fee ratio (Mfee) is measured by the ratio of management expense to total assets. Profit volatility (Pvol) is defined as the three-year volatility of the (total earnings before interest and tax)/(total assets ratio). Financial distress (Fina) is the Z-score of enterprise. Property rights type (Prt) is a dummy variable, represented as a dummy variable that equals 1 for state-owned enterprises and 0 for non-state-owned enterprises. The separation rate of two rights of actual controllers (Csep), is measured by the difference between the proportion of control rights and the proportion of ownership of listed enterprises owned by actual controllers. Equity balance (Bal), is calculated as the difference between the shareholding ratios of the second to fifth largest shareholders and the largest shareholder. Board dualization (Dual), is represented as a dummy variable with 1 for firms where the chairman and CEO are the same person and 0 for others. Board size (B size) is the number of directors on the board. The number of senior executives (Enum) is the number of senior executives of enterprise. The institutional environment (Ien) is the overall index of the marketization of Fan Gang.

3.2.4. Intermediary variables

To clarify, continuous R&D investment (CRDI) serves as an intermediary variable in this study, helping us analyze the relationship between GF and enterprises' sustainable green innovation. Following the approach used by He et al. (2017), we calculate the annual R&D investment of an enterprise in a given year (t) by multiplying the sum of specific R&D expenditures in the current year (t) and the previous year ($t-1$) by the year-on-year growth rate of the enterprise's R&D expenditure. The calculation formula is presented below:

$$CRDI_t = \frac{RDI_t + RDI_{t-1}}{RDI_{t-1} + RDI_{t-2}} \times (RDI_t + RDI_{t-1}) \tag{9}$$

3.2.5. Moderating variables

Financial constraint (FC) is one of the moderating variables in this study. Following the approach of Hadlock and Pierce (2010), we adopt the absolute value of the FC index as a measure of external financing constraints for enterprises. The specific calculation method is as follows:

$$FC = -0.737 \times Size + 0.043 \times Size^2 - 0.04 \times Age \tag{10}$$

Debt default risk (DDR) is the second moderating variable in this study. Drawing upon the research by Bharath and Shumway (2008) and Zhai et al. (2022), The standard deviation multiple of the firm's asset value relative to the default point is used to calculate the enterprise debt default risk.

3.3. Data description

This study is conducted based on panel data from micro-level data of Chinese A-share listed enterprises and macro-level data at the provincial level for the period of 2012–2020. The micro-level data of the enterprises primarily come from the China Stock Market & Accounting Research Database (CSMAR) database. The macro-level data at the provincial level are obtained from the "China Statistical Yearbook", "China Environmental Statistical Yearbook", "China Industrial Statistical Yearbook", "China Insurance Statistical Yearbook", "China Energy Statistical Yearbook" and "China Rural Statistical Yearbook." The study excludes samples with severe data missingness, financial sector samples and ST-classified samples. Table 2 provides descriptive statistics of the pertinent variables employed in this study.

Table 2. Descriptive statistics of main variables.

Variable	Number of observations	Mean	Std Dev	Minimum	Maximum
GF	14175	0.329	0.165	0.0910	0.879
SGI	14175	0.343	0.900	0	10.13
CRDI	14175	5.326	13.52	0	113.0
FC	14175	−3.764	0.296	−4.859	−2.114
DDR	14175	0.767	2.925	−119.1	7.674
Size	14175	22.54	1.317	19.35	26.98
Alr	14175	0.462	0.193	0.0480	1.154
Pvol	14175	0.0290	0.0400	0	0.394
Mfee	14175	0.0850	0.0630	0.00700	0.814
Fina	14175	4.077	4.434	−2.418	40.85
Prt	14175	0.420	0.494	0	1
Csep	14175	5.011	7.751	−68.93	41.01
Bal	14175	0.678	0.569	0.00500	2.745
Dual	14175	0.245	0.430	0	1
B size	14175	8.754	1.793	0	19
Enum	14175	6.756	2.587	0	24
Ien	14175	9.409	1.513	3.360	11.49

4. Analysis of empirical results

4.1. Benchmark regression analysis

To examine the relationship between GF development and sustainable green innovation in enterprises, this study employs fixed effect multiple regression analysis. The specific regression results are presented in Table 3.

Table 3. Benchmark regression results.

Variables	(1)	(2)	(3)	(4)
GF	0.347**	0.378**	0.378**	0.369**
	(2.19)	(2.34)	(2.34)	(2.32)
Size		0.243***	0.243***	0.240***
		(5.61)	(5.61)	(5.55)
Alr		−0.108	−0.108	−0.090
		(−1.12)	(−1.12)	(−0.93)
Pvol		−0.443**	−0.443**	−0.466**
		(−2.20)	(−2.20)	(−2.30)
Mfee		0.001	0.001	−0.012
		(0.00)	(0.00)	(−0.05)
Fina		0.004	0.004	0.004*
		(1.51)	(1.51)	(1.73)
Prt				0.032
				(0.54)
Csep				0.001
				(0.28)
Bal				0.048
				(1.35)
Dual				0.055*
				(1.83)
Bsize				−0.001
				(−0.05)
Enum				−0.005
				(−0.72)
Ien				−0.075***
				(−3.31)
Constant	0.229***	−5.199***	−5.199***	−4.459***
	(4.41)	(−5.35)	(−5.35)	(−4.49)
Observations	14,173	14,173	14,173	14,173
R−squared	0.601	0.608	0.608	0.609
Enterprise/Industry/Year FE	YES	YES	YES	YES

Note: ***, **, and * indicate significance at 1%, 5% and 10%, respectively.

Column 4 is considered as the benchmark regression for initiating the discussion. With a threshold of significance of 5%, the results of the baseline regression show a substantial positive correlation between GF and firms' sustainable green innovation. This indicates that GF is strongly linked with enterprise sustainable green innovation. This is highly consistent with Hypothesis 1 of theoretical analysis and verifies Hypothesis 1 to a certain extent. As discussed above, GF has a powerful function of economic resource allocation, which can tilt social and economic resources to enterprises' green development projects and enterprises engaged in green technology innovation, and promote the flow of financial resources to sustainable green innovation and green development projects. GF has

increased the number of available financing options and helps enterprises get funding for environmentally friendly development initiatives.

Furthermore, GF acts as an essential signal transmission mechanism, allowing enterprises to obtain a clear expectation of environmental regulatory policy direction, which reinforces their motivation for sustainable development and green innovation. Therefore, in the present economic development context that emphasizes green and sustainable development, it is critical for China and other countries to continue promoting GF development, establish a well-regulated GF market, and ensure the alignment and coordination of market development goals with policy planning. This group effort will support the social economy's sustainable growth and aid in resolving a number of environmental and social issues.

4.2. Intermediary effect test

The two-step regression method of intermediary effect is adopted for testing, and the test results are shown in Table 4. In addition, to further verify the intermediary effect test results of the two-step regression method, the bootstrap method is used to test the intermediary effect again, and the test results are shown in Table 5.

By columns 1 and 3 of Table 4, we observe that GF has a significant positive effect on enterprises' continuous R&D investment at a 5% significance level. This finding suggests that GF contributes to the promotion of enterprises' continuous R&D investment. The expectations of stability in green development and the availability of GF can motivate enterprises to invest in R&D. Moreover, market development further encourages enterprises' continuous R&D investment. This is owing to the fact that enterprises must continuously invest in R&D in order to keep their fundamental competitive advantage in a market economy.

Additionally, upon introducing the intermediary variable of continuous R&D investment, columns 2 and 4 of Table 4 in the regression results show that GF still has a significant impact on enterprises' sustainable green innovation at a 10% level, though the significance coefficient is somewhat lower. It's important to note that ongoing R&D investment has a 1% impact on enterprises' sustainable green innovation, suggesting that it acts as a partial mediator in the relationship between GF and sustainable green innovation in businesses. These findings are in alignment with our theoretical Hypothesis 2, which postulated that GF could stimulate sustainable green innovation in enterprises by facilitating continuous R&D investment. In this context, GF serves as an external driver that promotes knowledge generation and technological advances stemming from green R&D investment, thereby enhancing internal support for enterprises' green innovation and contributing to the promotion of sustainable green innovation in enterprises.

Table 4. Intermediary effect test results.

	(1)	(2)	(3)	(4)
VARIABLES	CRDI	SGI	CRDI	SGI
GF	6.405**	0.251*	6.240**	0.245*
	(2.12)	(1.75)	(2.06)	(1.74)
Size	4.454***	0.154***	4.541***	0.150***
	(6.90)	(3.98)	(7.04)	(3.84)
Alr	−0.219	−0.104	−0.119	−0.088
	(−0.16)	(−1.15)	(−0.09)	(−0.97)
Pvol	−6.479**	−0.314*	−6.799***	−0.331*
	(−2.52)	(−1.68)	(−2.64)	(−1.76)
Mfee	0.766	−0.014	0.789	−0.028
	(0.29)	(−0.06)	(0.29)	(−0.12)
Fina	0.100***	0.002	0.102***	0.002
	(3.40)	(0.72)	(3.45)	(0.94)
Prt			−0.623	0.044
			(−1.04)	(0.74)
Csep			0.016	0.000
			(0.43)	(0.14)
Bal			0.739	0.033
			(1.43)	(1.05)
Dual			0.213	0.050*
			(0.59)	(1.84)
Bsize			−0.272	0.005
			(−1.42)	(0.48)
Enum			−0.097	−0.003
			(−0.75)	(−0.49)
Ien			−0.961***	−0.056***
			(−3.01)	(−2.69)
CRDI		0.020***		0.020***
		(7.27)		(7.27)
Constant	−97.335***	−3.256***	−87.589***	−2.721***
	(−6.63)	(−3.78)	(−5.70)	(−3.09)
Observations	14,173	14,173	14,173	14,173
R−squared	0.698	0.635	0.699	0.636
Enterprise/Industry/Year FE	YES	YES	YES	YES

Table 5. Bootstrap test.

	Coefficient	Standard errors	Z-value	P-value	95% conf. interval
Mediation effect	0.1261***	0.0238	5.29	0.000	0.0794–0.1728
Direct effect	0.0854**	0.0426	2.01	0.045	0.0020–0.1689

Table 5 demonstrates that both the direct and indirect effects are statistically significant, and the confidence interval does not include 0, suggesting that continuous R&D investment functions as a mediator. This outcome aligns with the findings from the stepwise regression test, indicating a reliable and consistent intermediary effect.

4.3. Moderating effect test

To investigate whether financing constraints and debt default risk moderate the impact of GF on enterprises' sustainable green innovation, this study presents the regression results based on Model (3) and Model (4), as shown in Table 6.

From Table 6, it is apparent that GF has a significant positive relationship with both financing constraints and the interaction term between GF and debt financing. These results are significant at a 5% level or higher, indicating that financing constraints and debt default risk moderate the impact of GF on enterprises' sustainable green innovation. These results are in line with the theoretical hypotheses that were previously expressed, particularly Hypotheses 3 and 4, which contend that GF can help reduce high financing limitations and the danger of debt default while also encouraging businesses to adopt sustainable green innovation.

Furthermore, the results suggest that the promotion effect of GF on sustainable green innovation is more significant for enterprises facing high financing constraints and significant debt default risk. There are several reasons for this. First, GF provides more than just financing support for enterprises; it also reduces financing costs, thus easing their debt pressure. This is particularly beneficial for enterprises struggling with high financing constraints and risks of default.

Second, GF places greater emphasis on the environmental protection and social benefits of green investment and financing, making it more suitable for enterprises that prioritize green innovation. There is a natural synergy between green financial products and green innovation, wherein green financial investment and financing methods can better harness the commercial value of green innovation. Through green resource allocation, technological innovation and green production transformation within the value chain, enterprises can enhance their overall innovation capability and achieve sustainable transformation. Thirdly, under government and societal policy support and promotion, the marketization and influence of GF is growing, providing stronger support for enterprises to promote green innovation. With the help of policy support and promotion of GF, enterprises choose GF as an inevitable choice for achieving green innovation and sustainable development. Financial institutions and investors have also adopted green investment strategies, which amplify the market and social effects of green innovation.

Table 6. Results of moderating effect test.

Variables	(1)	(2)	(3)	(4)
GF	0.238*	0.233*	0.394**	0.385**
	(1.68)	(1.67)	(2.43)	(2.41)
FC	2.756***	2.727***		
	(6.64)	(6.63)		
GF*FC	0.887**	0.944**		
	(2.41)	(2.55)		
Size	0.209***	0.207***	0.252***	0.249***
	(5.12)	(5.06)	(5.71)	(5.66)
Alr	−0.121	−0.111	−0.079	−0.061
	(−1.33)	(−1.20)	(−0.81)	(−0.61)
Pvol	−0.128	−0.143	−0.439**	−0.461**
	(−0.66)	(−0.74)	(−2.17)	(−2.27)
Mfee	−0.408*	−0.409*	0.046	0.034
	(−1.69)	(−1.70)	(0.19)	(0.14)
Fina	−0.001	−0.001	0.004*	0.005*
	(−0.45)	(−0.26)	(1.71)	(1.93)
Prt		0.032		0.034
		(0.59)		(0.58)
Csep		0.000		0.001
		(0.20)		(0.32)
Bal		0.018		0.046
		(0.54)		(1.32)
Dual		0.040		0.056*
		(1.44)		(1.87)
Bsize		0.002		−0.000
		(0.16)		(−0.02)
Enum		−0.002		−0.005
		(−0.37)		(−0.76)
Ien		−0.065***		−0.076***
		(−2.94)		(−3.35)
DDR			0.008*	0.009*
			(1.79)	(1.79)
GF*DDR			0.115**	0.115**
			(2.13)	(2.14)
Constant	6.027***	6.530***	−5.438***	−4.697***
	(3.23)	(3.47)	(−5.46)	(−4.64)
Observations	14,173	14,173	14,173	14,173
R−squared	0.629	0.629	0.610	0.611
Enterprise/Industry/Year FE	YES	YES	YES	YES

5. Further analysis

5.1. Heterogeneity analysis

In this study, the concept of sustainable green innovation is further categorized into different types. According to Equation (5), the persistence of the number of green invention patents granted is used to measure substantive sustainable green innovation (SUSGI), while the persistence of the number of green utility patents granted is used to measure strategic sustainable green innovation (STSGI). Additionally, according to Equation (5), collaborative sustainable green innovation (CSGI) is measured by the persistence of the number of collaborative green invention patent applications in a given year as opposed to independent sustainable green innovation (ISGI), which is measured by the persistence of the number of independent green invention patent applications in a given year. Table 7 presents the results, which confirm that the promotion effect of GF, the intermediary role of continuous R&D investment and the heterogeneity mechanism of financing constraints are all observed across the four types of sustainable green innovation. However, it is found that enterprises with higher levels of debt default risk are more likely to engage in substantial and independent types of sustainable green innovation.

Enterprises with high debt default risk face greater market uncertainty and financial pressure, which may explain why they tend to prioritize substantial and independent types of sustainable green innovation. Such innovation adds value to enterprises by demonstrating their technical strength and innovation ability in green products and technologies, improving their business reputation and brand image and helping them secure more financial support and credit lines, consequently reducing the risk of debt default. Additionally, given the increasing marketization and social pressure for sustainable development, substantial and independent types of sustainable green innovation have become an inevitable choice for many enterprises.

Through this process, enterprises can improve their environmental awareness and image of social responsibility, meet the needs of society and the government for green development and enhance their market competitiveness, public trust and brand value, ultimately contributing to the long-term operation and development of the enterprise. Furthermore, in the context of high debt default risk, enterprises undertaking substantial and independent types of sustainable green innovation can access policy and financial support from national and local governments, such as government encouragement and backing for green technology, the environmental protection industry and clean energy. Government support can provide enterprises with financial subsidies, tax incentives and other policy guarantees and preferential measures, thereby reducing the financial and operational risks of their green innovation projects. In summary, enterprises with high debt default risk have a higher motivation to undertake substantial and independent types of sustainable green innovation due to their greater market uncertainty, financial pressure and their potential to access support for their sustainable green projects from governments.

Table 7a. Further analysis and test results (substantial and strategic).

Variables	(1) SUSGI	(2) CRDI	(3) SUSGI	(4) SUSGI	(5) SUSGI	(6) STSGI	(7) CRDI	(8) STSGI	(9) STSGI	(10) STSGI
GF	0.190***	6.240**	0.130**	0.131**	0.195***	0.110**	6.240**	0.083**	0.075*	0.113**
	(2.80)	(2.06)	(2.24)	(2.19)	(2.88)	(2.41)	(2.06)	(2.02)	(1.83)	(2.47)
FC				1.282***					0.705***	
				(7.57)					(7.04)	
GF*FC				0.344**					0.230**	
				(2.23)					(2.22)	
CRDI			0.010***					0.004***		
			(10.31)					(6.81)		
DDR					0.004**					0.001
					(2.23)					(0.27)
GF*DDR					0.040*					0.020*
					(1.92)					(1.66)
Constant	−1.690***	−87.589***	−0.838**	3.469***	−1.799***	−1.717***	−87.589***	−1.345***	1.123**	−1.728***
	(−4.28)	(−5.70)	(−2.40)	(4.52)	(−4.42)	(−6.44)	(−5.70)	(−5.29)	(2.36)	(−6.32)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173
R−squared	0.595	0.699	0.633	0.621	0.597	0.588	0.699	0.600	0.602	0.588
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table 7b. Further analysis and test results (independent and cooperative).

Variables	(1) ISGI	(2) CRDI	(3) ISGI	(4) ISGI	(5) ISGI	(6) CSGI	(7) CRDI	(8) CSGI	(9) CSGI	(10) CSGI
GF	0.219***	6.240***	0.149*	0.153*	0.225***	0.065**	6.240***	0.050**	0.044*	0.066***
	(2.65)	(2.06)	(1.91)	(1.88)	(2.72)	(2.33)	(2.06)	(2.04)	(1.83)	(3.90)
FC				1.426***					0.431***	
				(6.79)					(7.80)	
GF*FC				0.386**					0.133**	
				(2.20)					(2.37)	
CRDI			0.011***					0.002***		
			(9.30)					(6.92)		
DDR					0.005*					0.001
					(1.69)					(1.52)
GF*DDR					0.048*					0.007***
					(1.94)					(2.60)
Constant	−3.082***	−87.589***	−2.096***	2.655***	−3.214***	−0.248**	−87.589***	−0.037	1.487***	−0.267***
	(−6.18)	(−5.70)	(−4.62)	(2.72)	(−6.29)	(−2.02)	(−5.70)	(−0.32)	(5.98)	(−3.95)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173	14,173
R−squared	0.572	0.699	0.598	0.589	0.574	0.571	0.699	0.590	0.595	0.571
Enterprise FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

5.2. Endogeneity test

To address potential endogeneity bias caused by reverse causality, the benchmark regression results are re-estimated by incorporating an instrumental variable. Following the approach employed by Wang et al. (2023), the model includes an interaction term between the number of fixed telephones per 100 people in each province in 1984 (related to individuals) and the development of GF (related to time) as the instrumental variable. This helps mitigate the endogeneity issue and provides more robust estimates. The number of landlines in 1984 did not directly influence the ongoing green innovation of enterprises from 2012 to 2020, thereby meeting the homogeneity assumption of instrumental variables. The presence of fixed-line telephones in 1984 played a crucial role in facilitating information

transmission for the development of the Internet and financial sectors. Furthermore, this satisfies the principle of correlation of instrumental variables. The outcomes of the endogeneity test are presented in Table 8. In Column 8 of Table 8, the results successfully pass the correlation test of instrumental variables, and there is no significant difference between the sign and significance of the estimated coefficient of GF and the benchmark regression.

Table 8. Endogeneity test results.

	Instrumental variable method	
	Phase 1	Phase 2
GF		0.5397***(3.71)
Phase 1 *IV*	0.2725***(143.37)	
Control variables	YES	YES
Enterprise/Industry/Year FE	YES	YES
Anderson canon. corr. LM statistic		8563.802***
Cragg Donald Wald F Statistic		2.1e+04
Stock-Yogo weak test (10%)		16.380
Observations	13023	13023

5.3. Robustness test

To examine the credibility and stability of the regression results, this study conducted robustness tests by adding control variables (such as whether the board and management have financial backgrounds, overseas backgrounds or hold positions in shareholder units, the average age of management and the proportion of male managers), including provincial dummy variables, alternative measurement of the dependent variable (measuring continuous green innovation using the number of green patents obtained) and subsample analysis (excluding the samples from the year 2020 affected by the COVID-19 pandemic).

The results, as displayed in Tables 9 to 12, reveal that the earlier regression results are still significant, indicating that the outcomes are reasonably dependable and the regression results are somewhat robust.

Table 9. Robustness test (adding control variables).

	(1)	(2)	(3)	(4)	(5)
Variables	SGI	CRDI	SGI	SGI	SGI
GF	0.362**	6.152**	0.240*	0.227	0.379**
	(2.30)	(2.03)	(1.71)	(1.63)	(2.39)
FC				2.724***	
				(6.66)	
GF*FC				0.913**	
				(2.49)	
Mfin	0.026	−0.135	0.029	0.029	0.024
	(1.43)	(−0.48)	(1.64)	(1.64)	(1.32)
Moversea	−0.008	−0.348	−0.001	−0.014	−0.007
	(−0.31)	(−0.94)	(−0.03)	(−0.58)	(−0.29)
Cocurp	−0.014	−0.421	−0.005	−0.015	−0.014
	(−0.33)	(−0.71)	(−0.15)	(−0.41)	(−0.34)
Age	−0.005	0.016	−0.005	−0.003	−0.006
	(−0.91)	(0.18)	(−1.11)	(−0.46)	(−1.10)
Male	0.005**	0.026	0.004**	0.004**	0.005**
	(2.41)	(0.90)	(2.49)	(2.31)	(2.50)
CRDI			0.020***		
			(7.32)		
DDR					0.009*
					(1.85)
GF*DDR					0.117**
					(2.17)
Constant	−4.595***	−90.098***	−2.809***	6.324***	−4.812***
	(−4.29)	(−5.52)	(−3.02)	(3.45)	(−4.39)
Control variables	YES	YES	YES	YES	YES
Observations	14,173	14,173	14,173	14,173	14,173
R−squared	0.610	0.699	0.636	0.630	0.611
Enterprise/Industry/Year FE	YES	YES	YES	YES	YES

Table 10. Robustness test (adding dummy variable).

	(1)	(2)	(3)	(4)	(5)
Variables	SGI	CRDI	SGI	SGI	SGI
GF	0.384**	5.144***	0.282**	0.299**	0.401**
	(2.40)	(3.29)	(2.27)	(2.48)	(2.51)
FC				2.761***	
				(6.66)	
GF*FC				0.955***	
				(2.60)	
CRDI			0.020***		
			(7.28)		
DDR					0.008*
					(1.77)
GF*DDR					0.119**
					(2.19)
Constant	−4.515***	−85.319***	−2.822***	6.578***	−4.762***
	(−4.47)	(−14.59)	(−3.17)	(3.47)	(−4.64)
Control variables	YES	YES	YES	YES	YES
Observations	14,173	14,173	14,173	14,173	14,173
R−squared	0.610	0.702	0.637	0.631	0.612
Enterprise/Industry/Year FE	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES

Table 11. Robustness test (replacing the measurement method of the dependent variable).

	(1)	(2)	(3)	(4)	(5)
Variables	SGI	CRDI	SGI	SGI	SGI
GF	1.933**	6.240**	0.990	1.015	2.023**
	(2.41)	(2.06)	(1.46)	(1.45)	(2.53)
FC				18.663***	
				(6.74)	
GF*FC				6.944***	
				(3.11)	
CRDI			0.160***		
			(9.48)		
DDR					0.030
					(0.64)
GF*DDR					0.603*
					(1.91)
Constant	−33.716***	−87.589***	−19.844***	41.286***	−34.506***
	(−5.49)	(−5.70)	(−3.76)	(3.38)	(−5.51)
Control variables	YES	YES	YES	YES	YES
Observations	13,999	14,173	13,999	13,999	13,999
R−squared	0.675	0.699	0.721	0.701	0.677
Enterprise/Industry/Year FE	YES	YES	YES	YES	YES

Table 12. Robustness test (excluding years).

	(1)	(2)	(3)	(4)	(5)
Variables	SGI	CRDI	SGI	SGI	SGI
GF	0.318*	5.443*	0.205	0.148	0.328*
	(1.87)	(1.74)	(1.40)	(1.05)	(1.92)
FC				3.057***	
				(6.47)	
GF*FC				1.121***	
				(2.84)	
CRDI			0.021***		
			(6.89)		
DDR					0.014**
					(2.24)
GF*DDR					0.138**
					(2.20)
Constant	−4.767***	−81.855***	−3.077***	6.971***	−5.104***
	(−4.19)	(−5.07)	(−3.03)	(3.34)	(−4.40)
Control variables	YES	YES	YES	YES	YES
Observations	11,875	11,875	11,875	11,875	11,875
R−squared	0.617	0.682	0.645	0.641	0.620
Enterprise/Industry/Year FE	YES	YES	YES	YES	YES

6. Conclusions and suggestions

6.1. Conclusions

Promoting the development of GF is a critical choice for China and nations across the world in the quest of reaching the goal of "peak carbon emissions and carbon neutrality" to boost green and low-carbon economic development. In order to examine the mechanisms and pathways via which GF has an impact on businesses' sustainable green innovation, this study uses China as a case study. Specifically, this study explores the impact of GF on enterprises' continuous R&D investments, financial constraints and debt default risk. Using panel data from the micro-level of Chinese A-share listed enterprises and the macro-level of provincial data from 2012 to 2020, we employ a fixed-effects model to conduct in-depth empirical testing. The results reveal that the development of GF positively affects enterprises' sustainable green innovation. Moreover, enterprises' financing restrictions and debt default risk play moderating roles, influencing the relationship between green financing growth and green innovation. Additionally, enterprises' continuous R&D investment is found to mediate this relationship. Our findings contribute to the theoretical discussions on the impact of GF on enterprises' sustainable green innovation, while also providing practical implications for government policymakers and enterprises.

Our empirical results demonstrate a significant positive effect of GF on enterprises' sustainable green innovation. Our research of the mediation between GF and firms' sustainable green innovation reveals that continuous R&D investment serves as a partial intermediary, suggesting that GF encourages enterprises' sustainable green innovation by increasing their continuous R&D expenditure. Our research of moderation also demonstrates that the debt default risk and financing constraints faced

by businesses have a strong moderating effect on the connection between GF and business sustainable green innovation. Specifically, for enterprises facing high financing constraints and significant debt default risk, the promotion impact of GF on their sustainable green innovation is more pronounced.

Moreover, we investigated the impact of GF and the intermediary effect of continuous R&D investment on four types of sustainable green innovation, categorized as strategic, substantive, independent and collaborative. Our findings suggest that the promotion effect of GF, the intermediary effect of continuous R&D investment and the heterogeneous mechanism of financing constraints are evident across the four types of continuous green innovation. It's interesting to note that businesses with a larger risk of debt failure are more inclined to pursue independent, substantial forms of sustainable green innovation.

However, we acknowledge limitations in the depth of result interpretation and the richness of research content in our study. Future research could further investigate the interactive relationship and mechanisms between GF and enterprises' sustainable green innovation, incorporating data from other countries and employing qualitative research methods. Overall, our study contributes important insights into understanding the effect of GF on enterprises' sustainable green innovation and has significant implications for policymakers and enterprises striving toward sustainable development.

6.2. Suggestions

The conclusions of our study have significant policy ramifications, particularly for emerging nations. Based on our findings, we suggest the following policy recommendations: First, nations should actively promote the further development of GF, providing external financial support to enterprises engaged in sustainable green innovation. This will assist in facilitating the transition to a green economy and empower the achievement of "carbon peaking" and "carbon neutrality" goals. Regulation on GF can also be improved to ensure funding flows toward enterprises involved in green innovation activities and green transformation. Second, GF can facilitate enterprises in sustaining their R&D investments, thereby supporting sustainable green innovation. Nations can create a conducive socio-economic environment for enterprises to sustain their R&D investments. This will enable enterprises to excel in sustainable green innovation and drive the transition toward a green economy. Last, our results highlight that GF plays a more significant role in supporting sustainable green innovation activities of enterprises that face high financing constraints and debt default risks. Therefore, nations can focus on the development status of enterprises that encounter difficulties in green transformation and face financial constraints. Targeted policies can be formulated to guide these specific types of enterprises toward sustained green innovation, facilitating their transition to a green economy.

In summary, our study contributes to the ongoing research on the role of GF in supporting enterprises' sustainable green innovation. The policy recommendations outlined here can assist emerging nations in their efforts toward achieving "carbon peaking" and "carbon neutrality" goals while enabling sustainable economic growth.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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