sciendo

DOI: 10.2478/eces-2023-0007 ECOL CHEM ENG S. 2023;30(1):93-101

Min NIU[1] and Dan-Dan XU[1*]

RESEARCH ON THE LOW CARBON OF GFD: FROM THE PERSPECTIVE OF GL BASED ON ENVIRONMENTAL PROTECTION

Abstract: Enhancing the low-carbon effect of green finance development (GFD) is an effective way for China to accelerate the comprehensive deepening of supply side structural reform, better realise the high-quality development of green economy and better protect the environment. Therefore, based on the green technology innovation theory and endogenous growth theory, from the four dimensions of green innovation (GI) in the GLOBIO model, the unbalanced panel data of 8976 manufacturing listed companies from 2009 to 2021 were used. This paper deeply explores the low-carbon effect of GI on the development of green finance (GF) in China's manufacturing industry. The results show that: on the whole, GI based on environmental protection has a significant incentive effect on the low-carbon effect of GFD. Compared with green material innovation and green process innovation, green product design innovation and green equipment innovation have more incentive effect. Further analysis shows that green product design innovation and green equipment innovation can produce incremental effect on the low-carbon effect of green financial development through green material innovation. The conclusion not only provides empirical support for green technology innovation theory and endogenous growth theory, but also provides effective evidence for the path of GF to achieve low-carbon development.

Keywords: GI, GFD, low carbon effect, environmental protection

Introduction

Green finance (GF) is a new financial model formed in the new era of economic development. From the actual development of China's green industry, the high-tech related to green industry development is relatively backward, especially the manufacturing industry in the field of green economy. Compared with western developed countries, the output of high-end green industry chain is still relatively limited, and the high-end green industry chain generally lags behind. In the era of knowledge economy, among the core elements of competitive advantage, green industry (GI) has replaced the traditional production factors, and its status has become increasingly prominent, and it is an important strategic capital for enterprises [1, 2]. As an important element of the core competitiveness of enterprises, the reasonable allocation of GI is more important than the development investment of low-carbon effect of GF. It is the endogenous driving force for the development of GF, which not only has strong value creation ability, but also has certain monopoly [3]. The key factor of Green finance development (GFD) is to make use of the green financial factors to promote the development of green enterprises. Only by making reasonable and effective

[1] Zhengzhou Shengda University, Xinzheng, Henan 451191, China, ORCID: MN 0009-0000-8320-249X, DDX 0009-0005-1737-1101

[*] Corresponding author: 100325@shengda.edu.cn

use of production input factors such as GI can enterprises improve the low-carbon effect of GFD, create value, maintain their competitive advantages [4].

Wu studied from the definition, composition and classification of GI and its low-carbon effect on the development of national GF and the low-carbon effect of GFD, and achieved rich research results [5]. However, the research perspective is more focused on the low-carbon effect of one or the whole GI on the development of GF. There are some difference in the contribution of different GI to the low-carbon effect of GFD [6], and complementarity among different types of GI investment. In addition, combined with China's institutional background, the low-carbon effect of GI in different industries and different natures may produce heterogeneous effect on the development of GF [7]. The exploration of these problems has important theoretical and practical significance for enriching endogenous growth theory and promoting high-quality development of enterprises and countries. Based on the endogenous growth theory and green technology innovation theory, this paper establishes a theoretical framework of the low-carbon effect of GI on the development of GF, including green material innovation, green product design innovation, green equipment innovation and green technology innovation. Therefore, we put forward the following three hypothesis.

Theoretical analysis and hypothesis

Low carbon effect of GI and GFD

Assuming that a company produces goods and services according to the following GLOBIO model: $Y = A(IC,H,\theta)F(L,K)$ where Y, H, L, K and A represent the added value of enterprise production, green product design innovation, labour force, material capital, and low carbon effect of GFD [8]. θ means other factors that determine the low-carbon effect of GFD. F is the continuous function of L and K, and A are the increasing functions of GI and other factors, which reflects that GI can improve the efficiency of enterprises, so as to improve the low-carbon effect of GFD. Equation (1) reflects that the productivity improvement of GI, including green product design innovation, which is accompanied by diminishing marginal return:

$$\frac{\partial A}{\partial IC} > 0,\ \frac{\partial^2 A}{\partial^2 IC} < 0,\ \frac{\partial A}{\partial H} > 0,\ \frac{\partial^2 A}{\partial^2 H} < 0 \text{ and } \frac{\partial A}{\partial IC \partial H} = \frac{\partial A}{\partial H \partial IC} > 0 \qquad (1)$$

According to the theory of green technology innovation, the establishment of green equipment plays an effective role in reducing the transaction cost of enterprises, so enterprises should invest in green equipment innovation to improve the establishment of financial information, and then improve the production efficiency of economic entities [9, 10]. As the core of GI, green material innovation will eventually form the core competitiveness. Enterprises can obtain various GI and good business environment from the outside by investing in green product design innovation, green equipment innovation related to enterprises, and green process innovation related to enterprise organisation and management efficiency, so as to obtain competitive advantages to a large extent, thus improving the low carbon effect of GFD [11]. When an enterprise has enough capital, whether it invests in GI to enhance the low-carbon effect of the development of GF depends on the relative marginal income of GI relative to the development of low-carbon effect of GF [12].

Equation (2) reflects the difference of marginal return (*DMR*) between GI and the GFD:

$$DMR = F(L,K)\frac{\partial A(IC,H,\theta)}{\partial IC} - A(IC,H,\theta)F_K(L,K) \tag{2}$$

The higher the *DMR*, it shows that enterprises are more inclined to invest in GI to enhance the low-carbon effect of GFD. This incentive effect will change with the types of GI:

$$\frac{\partial DMR}{\partial K} = F_K(L,K)\frac{\partial A(IC,H,\theta)}{\partial IC} - A(IC,H,\theta)F_{KK}(L,K) > 0 \tag{3}$$

Equation (4) reflects the marginal return of *DMR* to physical capital. From the above formula, with the increase of the development of low-carbon effect of GF, the marginal income of GFD decreases, and the improvement of marginal income of GI leads to the increase of low-carbon effect of GFD, that is:

$$\frac{\partial A(IC,H,\theta)}{\partial IC} > 0 \tag{4}$$

According to the endogenous growth theory, enterprises must obtain the necessary GI to ensure the endogenous technological progress, so as to realise the sustainable development of enterprise economy [13]. Therefore, through equations (3) and (4), we can find that the development of higher low-carbon effect of GF leads to the increase of *DMR*, which makes enterprises more likely to invest in GI, and finally improves the low-carbon effect of GFD. In order to pursue sustainable development benefits, enterprises must reasonably invest and utilise GI to enhance the low-carbon effect of their own GFD. Therefore, we propose Hypothesis H1:

H1: the investment in GI will have an incentive effect on the low-carbon effect of the development of GF.

Complementary effects

The output of firm *i* at time *t* can be described by Cobb Douglas production function:

$$Q_{it} = A_{it}L_{it}^{\beta_l}K_{it}^{\beta_k}M_{it}^{\beta_m} \tag{5}$$

In equation (5), Q_{it}, M_{it} and K_{it} respectively represent the output, physical and GI input, and L_{it} represents its labour input, which is measured by the number of employees. A_{it} is a method to measure the level of efficiency, commonly known as the low carbon effect of GFD [14].

A labour advantage that is significantly greater than (less than) zero means that returns to scale increase (decrease). When the proportional returns of all input elements are constant, namely, the return of the input factors is constant, that is $\beta_l + \beta_k + \beta_m = 1$. The production function is:

$$q_{it} - l_{it} = \beta_0 + \beta_k(k_{it} - l_{it}) + \beta_m(m_{it} - l_{it}) + \omega_{it} + \eta_{it} \tag{6}$$

Finally, the calculation method of low carbon effect of GFD is proposed:

$$\hat{TFP}_{it} = (q_{it} - l_{it}) - (\hat{\mu} - 1)l_{it} - \hat{\beta}_k(k_{it} - l_{it}) - \hat{\beta}_m(m_{it} - l_{it}) \tag{7}$$

The low-carbon effect of GFD is estimated by formula (7) to evaluate the impact of GI. According to the theory of green technology innovation, green equipment innovation can help enterprises maintain their core competitiveness [15]. According to the classification method of intangible assets in the literature review of GI and low-carbon effect of GFD, GI is quantified as green material innovation, green product design innovation, green equipment innovation and green process innovation, and the regression of low-carbon effect of GFD is shown in formula:

$$\hat{TFP}_{it} = \gamma_1 IC_{it} + \gamma_2 HC_{it} + \gamma_3 BC_{it} + \gamma_4 OC_{it} + X_{it} + \varepsilon_{it} \tag{8}$$

where *HC* represents green product design innovation, *BC* represents green equipment innovation, and *OC* represents green process innovation. In addition to GI, it also includes a set of control variables, expressed by X_{it}.

From the perspective of green technology innovation theory, a good grasp of the dissemination of credit information is conducive to reliable cooperative partnership, the formation of core competitiveness of enterprises, easier to absorb foreign investment, introduce more advanced green material innovation investment, and more easily attract talents to join in, which indirectly increases the investment in green product design innovation, making the low-carbon effect of the development of GF rise steadily [16]. Therefore, we propose the hypothesis H2 that:

H2: green product design innovation and green equipment innovation can affect the promotion of low-carbon effect of GFD.

Heterogeneity effect

Endogenous growth theory holds that the economic growth rate of a company depends on the growth of knowledge. Organisational management mode and organisational management efficiency are heterogeneous resources of enterprises. The growth of knowledge will enhance management efficiency and realise human green innovation under the new environment. Compared with non-state-owned enterprises, the flexibility of state-owned enterprises' system and mechanism is poor, and excessive investment hinders their own green innovation ability, and the investment in green material innovation is greatly reduced.

There are significant differences in industry distribution of GI. China's manufacturing industry is a high-tech industry with high R&D investment intensity in the national economy, especially in the computer, communication and other electronic equipment industries, and its R&D capital investment intensity is more sufficient. Compared with other industries, R&D investment accounts for a large proportion of GI investment in this industry, which contributes more to the low carbon effect and economic growth of GF. Based on the above reasoning and analysis, we propose the hypothesis H3:

H3: The impact of GI input on the low-carbon effect of China's GFD shows obvious heterogeneity.

Research design and model setting

Sample selection and data sources

The sample data of this paper comes from the manufacturing listed companies from 2009 to 2021. Excluding the special listed companies of ST and *ST and the samples with

missing data, the panel data of 1215 enterprises are obtained after data collation. In this paper, the tail of all the continuous variables is processed. The financial indicators of listed companies are mainly from wind database, the basic information of enterprises and their own characteristics data are mainly from CNRDS database, and the rest data are all from CSMAR database. SPSS is used for data sorting and STATA is used for empirical analysis.

The control variables used in this paper include: The age of the enterprise, which is expressed by the year of the enterprise minus the year of establishment, and then expressed by logarithm; The capital intensity (*CI*) is expressed by dividing the amount of fixed capital by the number of employees and taking logarithm; Scale is measured by the logarithm of the number of employees; The financial market power (*SL*) of an enterprise is expressed by the turnover rate index of total capital and logarithm; The ratio of capital to debt (*ALR*) represents the degree of corporate leverage, which is represented by the ratio of total debt to the development of low-carbon effect of GF; Enterprises are classified into state-owned enterprises and other enterprises according to the nature of property rights (*STATE*), and judged by the actual legal person of enterprises; Profit can be directly obtained from the financial statements of the enterprise and logarithm is taken; Enterprise capital mobility (*ASLIQ*) can be calculated by the corresponding financial data in financial statements and expressed by taking logarithm. Specifically, the symbols and names of the main variables are shown in Table 1.

Table 1

Symbols and names of main variables

Variable symbol	Variable name
INNO	Green material innovation
HUMAN	Green product design innovation
$REPU_1$ & $REPU_2$	Green equipment innovation
OC	Green process innovation
AGE	Age of enterprise
CI	Capital intensity
SCALE	Enterprise scale
SL	Financial market power
ALR	Capital debt ratio
STATE	According to the nature of property rights
PROFIT	Total profit
ASLIQ	Liquidity of enterprise capital

Model construction

This paper classifies GI into green material innovation, green product design innovation, green equipment innovation and green process innovation. In the model, industry fixed effect and time fixed effect are used to test the impact of green material innovation, green product design innovation, green equipment innovation and green process innovation on the low-carbon effect of GFD. Model 1 was constructed as follows:

$$TFP_LP_{it} = \alpha_0 + \alpha_1 INNO_{it} + \alpha_2 HUMAN_{it} + \alpha_3 REPU_{it} + \alpha_4 OC_{it} + \alpha_5 AGE_{it} + \alpha_6 CI_{it} + \alpha_7 SCALE_{it} + \alpha_8 SL_{it} + \alpha_9 ALR_{it} + \alpha_{10} STATE_{it} + \alpha_{11} PROFIT_{it} + \alpha_{12} ASLIQ_{it} + \mu_t + \nu_i + \varepsilon_{it} \quad (9)$$

In order to test that green material innovation and green product design innovation are complementary in promoting the low-carbon effect of GFD, that is, green product design

innovation may affect the promotion of low-carbon effect of GFD through GI channels. Model 2 was constructed as follows:

$$TFP_LP_{it} = \alpha_0 + \alpha_1 INNO_{it} + \alpha_2 HUMAN_{it} + \alpha_3 INNO_{it} \times HUMAN_{it} + \alpha_4 REPU_{it} + \alpha_5 OC_{it} + \alpha_6 \mathrm{AGE}_{it} + \alpha_7 CI_{it} + \alpha_8 SCALE_{it} + \alpha_9 SL_{it} + \alpha_{10} ALR_{it} + \alpha_{11} STATE_{it} + \alpha_{12} PROFIT_{it} + \alpha_{13} ASLIQ_{it} + \mu_t + \nu_i + \varepsilon_{it} \quad (10)$$

In order to test that green material innovation and green equipment innovation are complementary in promoting the low-carbon effect of GFD. Model 3 was constructed as follows:

$$TFP_LP_{it} = \alpha_0 + \alpha_1 INNO_{it} + \alpha_2 HUMAN_{it} + \alpha_3 REPU_{it} + \alpha_4 REPU_{it} \times INNO_{it} + \alpha_5 OC_{it} + \alpha_6 AGE_{it} + \alpha_7 CI_{it} + \alpha_8 SCALE_{it} + \alpha_9 SL_{it} + \alpha_{10} ALR_{it} + \alpha_{11} STATE_{it} + \alpha_{12} PROFIT_{it} + a_{13} ASLIQ_{it} + \mu_t + \nu_i + \varepsilon_{it} \quad (11)$$

Empirical test results and analysis

Baseline regression analysis

According to Table 2, the regression result Column (1) shows that both the main variables and the explained variables are significant and the coefficients are positive. On the whole, enterprises have positive incentive effects on green material innovation, green product design innovation, green process innovation and green equipment innovation. It can be preliminarily judged that hypothesis H1 is correct.

Table 2

Basic regression results of low carbon effect of GI and GFD

Variable name	(1)	(2)	(3)	(4)	(5)
INNO	0.024** (0.005)	0.035* (0.007)			
$HUMAN_1$	0.081*** (0.006)		0.061*** (0.002)		
$HUMAN_2$	0.072*** (0.026)		0.058*** (0.006)		
$REPU_1$	0.027*** (2.251)			0.043** (2.014)	
$REPU_2$	0.029*** (2.053)			0.042** (2.171)	
OC	0.019* (0.014)				0.024* (0.014)
Constant	2.126*** (0.057)	2.318*** (0.057)	2.130*** (0.057)	2.157*** (0.057)	2.176*** (0.057)
N	8976	8976	8976	8976	8976
R-squared	0.079	0.069	0.057	0.036	0.029
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes

Note: ***, ** and * denote the significance level of 1 %, 5 % and 10 %, respectively. The robust standard error is shown in brackets

The results show that there is a positive significant relationship between all GI and the low-carbon effect of GFD. There are significant differences in the regression coefficient of

low-carbon effect between GI and GFD. By comparing the regression coefficients of low-carbon effect between GI and GFD, it is not difficult to find that the average coefficient of green product design innovation and green equipment innovation is relatively high, that is to say, compared with other types of GI, green equipment innovation and green product design innovation have more obvious promoting effect on the total productivity of enterprises.

Further analysis

Through Column (1) and Column (5) of the regression results of the Table 2, we can find that the low carbon effect of GFD significantly enhances the elasticity coefficient of $HUMAN_1$, $HUMAN_2$, $REPU_1$ and $REPU_2$, that is, through the investment of green material innovation, the impact of green equipment innovation and green product design innovation on the low-carbon effect of GFD can be enhanced, N represents the sample size.

Table 3

Regression results of low-carbon effect between GI and the GFD for enterprises with added cross-terms

Variable name	(1)	(2)	(3)	(4)
INNO	0.013** (0.006)	0.013** (0.003)	0.014** (0.012)	0.019** (0.018)
$HUMAN_1$	0.076*** (0.026)		0.071*** (0.032)	0.068*** (0.024)
$HUMAN_2$		0.072*** (0.031)	0.068*** (0.037)	0.064*** (0.026)
$INNO \times HUMAN_1$	0.094*** (0.043)			
$INNO \times HUMAN_2$		0.091*** (0.051)		
$REPU_1$	0.036*** (2.299)	0.031*** (2.214)	0.034*** (2.215)	
$REPU_2$	0.027*** (2.156)	0.022*** (2.118)		0.038*** (2.105)
$INNO \times REPU_1$			0.048*** (2.193)	
$INNO \times REPU_2$				0.053*** (2.146)
Constant	2.225*** (0.078)	2.238*** (0.081)	2.123*** (0.073)	2.163*** (0.071)
N	8976	8976	8976	8976
R-squared	0.096	0.095	0.091	0.092
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes

In order to confirm that green product design innovation, green equipment innovation and green material innovation are complementary in promoting the low-carbon effect of GFD, this paper adds cross items on the basis of benchmark regression, and carries out regression analysis by using the above Formula (10) in Model 2 and Formula (11) in Model 3, as shown in Table 3. The regression results showed that: *INNO* × *HUMAN* coefficient is about 0.094, which is significantly increased compared with the original *HUMAN* coefficient; The highest *INNO* × *REPU* coefficient is about 0.053, which is significantly increased compared with the original *REPU* coefficient, that is to say, the regression

coefficients of the two cross terms have reached a high level on the whole. Therefore, the low-carbon effect of green product design innovation, green equipment innovation and green material innovation in stimulating the GFD are complementary. Therefore, it is assumed that H2 is correct.

Policy recommendations

Based on the above conclusions, this paper puts forward the following suggestions:

(1) The government should guide enterprises to actively produce green products to reduce greenhouse gas emissions. At the same time, enterprises should be encouraged to accelerate the pace of technological green innovation, constantly develop new technologies and new methods, and enhance their green innovation capacity. In addition, the government should also increase support for the green manufacturing industry and provide a good environment for enterprises.
(2) Enterprises should establish "green" consciousness, strengthen the cultivation of their own ability to save energy and reduce emissions, attach importance to environmental protection work, start from the source, and avoid the production mode of high energy consumption and high material consumption.
(3) Improve the construction of relevant laws and regulations, and strengthen the supervision and inspection of the implementation effect of low-carbon policies.
(4) Establish a scientific and reasonable evaluation mechanism and give full play to the role of incentive mechanism.

Conclusion

How to make good use of GI can better improve the low-carbon effect of GFD is the main question of this paper. Based on the integration of green technology innovation theory and endogenous growth theory, according to the GLOBIO model, using the manufacturing listed company samples from 2009 to 2021, this paper comprehensively explores the impact of GI on the low-carbon effect of GFD in China's manufacturing industry. On the whole, green product design innovation, green equipment innovation, green material innovation and green process innovation all have significant incentive effect on the low-carbon effect of GFD, but different types of GI have different effects it. Specifically, compared with green material innovation and green process innovation, green product design innovation and green equipment innovation have more obvious incremental effect on the low-carbon effect of GFD. Green material innovation, green product design innovation and green equipment innovation are complementary in improving the low-carbon effect of GFD, that is, green product design innovation and green equipment innovation can produce incentive effect on the low-carbon effect of GFD through green material innovation.

References

[1] Li SS, Wang GWJ, Li Y, Geng JC, Zhu JQ. Analysis and prediction of the coupling and coordinated development of green finance - environmental protection in China. Sustainability. 2022;14(15):9777. DOI: 10.3390/su14159777.
[2] Wu CH, Tsai SB, Liu W, Shao XF, Sun R, Wacławek M. Eco-technology and eco-innovation for green sustainable growth. Ecol Chem Eng S. 2021;28(1):7-10. DOI: 10.2478/eces-2021-0001.
[3] Feng LG, Shang S, An SF, Yang WL. The spatial heterogeneity effect of green finance development on carbon emissions. Entropy. 2022;24(8):1042. DOI: 10.3390/e24081042.

[4] Lu M, Sun GF, He ZC. Analysis and evaluation of factors influencing the low-carbon effect of urban high-rise settlement planning schemes based on AHP-fuzzy comprehensive evaluation method. Mathematical Problems Eng. 2022;(2022):9529110. DOI: 10.1155/2022/9529110.
[5] Wu CH. An empirical study on discussion and evaluation of green university. Ecol Chem Eng S. 2021;28(1):75-87. DOI: 10.2478/eces-2021-0007.
[6] Sun WB, Du HB, Li JL, Jiao YF, Liu L. The low-carbon effect measurement of the structural adjustment of the ice and snow industry based on artificial intelligence. Security Communication Networks. 2022;(2022):7618340. DOI: 10.1155/2022/7618340.
[7] Xiong Q, Sun D. Influence analysis of green finance development impact on carbon emissions: an exploratory study based on fsQCA. Environ Sci Pollut Res Int. 2022;1-12. DOI: 10.1007/s11356-021-18351-z.
[8] Yang Z, Shi Q, Lv X, Shi Q. Heterogeneous low-carbon targets and energy structure optimization: Does stricter carbon regulation really matter? Structural Change Economic Dynamics. 2022;60:329-43. DOI: 10.1016/j.strueco.2021.12.008.
[9] Lv CC, Bian BC, Lee CC, He ZW. Regional gap and the trend of green finance development in China. Energy Economics. 2021;102. DOI: 10.1016/j.eneco.2021.105476.
[10] Zheng GW, Siddik AB, Masukujjaman M, Fatema N, Alam SS. Green finance development in Bangladesh: The role of Private Commercial Banks (PCBs). Sustainability. 2021;13(2). DOI: 10.3390/su13020795.
[11] Zhang ZY, Yu LY. Dynamic optimization and coordination of cooperative emission reduction in a dual-channel supply chain considering reference low-carbon effect and low-carbon goodwill. Int J Environ Res Public Health. 2021;18(2):1-33. DOI: 10.3390/ijerph18020539.
[12] Jiang LL, Wang H, Tong AH, Hu ZF, Duan HJ, Zhang XL. The measurement of green finance development index and its poverty reduction effect: Dynamic panel analysis based on improved entropy method. Discrete Dynamics Nature Soc. 2020;1-13. DOI: 10.1155/2020/8851684.
[13] Zhang Y, Wei W. Does blockchain technology promote the development of green finance? Evidence from China. 2019 International Conference on Management Science and Industrial Economy (MSIE 2019). 2020. DOI: 10.2991/msie-19.2020.41.
[14] Zhai Y, Nam KY, Malang L. ADB's experience in clean energy finance. Financing Clean Energy Developing Asia. 2021;1:3. DOI: 10.1787/55d14a84-en.
[15] Chen S, Shi A, Wang X. Carbon emission curbing effects and influencing mechanisms of China's Emission Trading Scheme: The mediating roles of technique effect, composition effect and allocation effect. J Cleaner Production. 2020;264:121700. DOI: 10.1016/j.jclepro.2020.121700.
[16] Yu BQ, Wang J, Lu XM, Yang HT. Collaboration in a low-carbon supply chain with reference emission and cost learning effects: Cost sharing versus revenue sharing strategies. J Cleaner Prod. 2019;250(C). DOI: 10.1016/j.jclepro.2019.119460.