The Impact of Digital Financial Inclusion on Green Innovation in the Yangtze River Delta

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Abstract. Digital financial inclusion is developing rapidly, and studies have confirmed that it has brought great impact on science and technology innovation. Taking green innovation as a new perspective, this paper explores the impact of digital inclusive finance on green innovation in the Yangtze River Delta from 2011 to 2020 based on the use of Eviews software, and concludes that digital inclusive finance has a significant positive effect on green innovation in the YRD region. It is further analyzed to conclude that both the sub-dimensions of breadth of coverage and depth of use of digital financial inclusion play a significant positive effect on green innovation.

Keywords: Digital financial inclusion, green innovation, the Yangtze River Delta.

1. Introduction

The 18th CPC National Congress clearly puts forward that "scientific and technological innovation is the strategic support for improving social productivity and comprehensive national strength, and must be placed at the core of the overall situation of national development." Scientific and technological development and innovation cannot be separated from the support of resources, based on the scarcity of resources and the protection of the environment, the Fifth Plenary Session of the 18th CPC Central Committee put forward the concept of "green development". The Sixth Plenary Session of the 19th CPC Central Committee put forward the dual requirements of "promoting scientific and technological self-reliance and self-improvement" and "adhering to the harmonious coexistence of man and nature". Green innovation, as a combination of innovation-driven and green development two national development strategies, is one of the core contents of promoting the construction of ecological civilization, and has gradually become a hotspot of concern for all sectors of society.

In the context of "dual-carbon" and innovation-driven development, green innovation is a complex activity involving multiple parties and mutual integration. Finance can effectively promote the development of innovation through resource allocation and other means. However, due to the more prominent structural problems in China's traditional finance, there is an imbalance between the financing model and the financial supply, and the financing constraints often make it difficult to meet the needs of enterprises to obtain sufficient capital and perfect financial services for green innovation [1].Digital financial inclusion is an important carrier to promote the development of inclusive finance in China, which is an emerging financial service model for traditional financial institutions or Internet enterprises to utilize modern information technology, such as Internet technology and mobile communication technology, to realize capital financing, payment, investment and information intermediary services, with the characteristics of breaking the constraints of space and time, low thresholds, convenient transactions, low transaction costs, etc., which can effectively expand the coverage and penetration rate of finance, and improve the efficiency of the allocation of financial resources [2].

In recent years, many provinces and municipalities in China have proposed to vigorously develop digital financial inclusion to provide financial technology support for regional economic development [3]. Across the country, there is a growing emphasis on integrating digital financial inclusion with regional innovation in the advancement of the digital economy [4]. Studies [5] have shown that the development of digital financial inclusion can effectively promote regional innovation. In the context

of the green development concept and the "dual-carbon" drive, the question of whether digital financial inclusion can significantly influence regional green innovation has become a matter for further research.

The Yangtze River Delta, including Shanghai, Jiangsu, Zhejiang and Anhui provinces, is one of the regions with the most active economic development, the highest degree of openness and the strongest innovation capacity in China, and plays a pivotal strategic position in the overall situation of the country's modernization and all-round opening-up pattern. In terms of regional innovation cooperation, three provinces and one city in the Yangtze River Delta signed the Strategic Cooperation Agreement on Accelerating the Construction of a Regional Innovation Community in the Yangtze River Delta, joining hands to undertake major scientific and technological innovation tasks, promoting the construction of large-scale scientific and technological devices and the sharing of scientific and technological resources within the region, as well as piloting the universal redemption of science and technology innovation vouchers within the Yangtze River Delta. The Yangtze River Delta is also one of the fastest growing regions in China in terms of digital economy. The "Yangtze River Delta Digital Trunk Road", originating in Qingpu, Shanghai, relies on the G50 trunk corridor and the cities along the route to collaborate to create a first-class new infrastructure for digital innovation and development belt [4]. Driven by policies, digital finance in the Yangtze River Delta region has developed rapidly, and the regional innovation capacity and economic development level have improved significantly. Scholars have already found that digital financial inclusion has an obvious role in promoting the development of technology-intensive industries in the Yangtze River Delta and the enhancement of regional innovation capacity. In terms of innovative development, the Yangtze River Delta also upholds the concept of green development. The Outline of the Plan for the Integrated Development of the Yangtze River Delta clearly states that priority should be given to ecological protection, and that the protection and restoration of the ecological environment should be accorded a high priority, in an effort to build a green and beautiful Yangtze River Delta. Under the above background, whether the development of digital finance can enhance the green innovation capacity of the Yangtze River Delta region is an important research direction.

2. Literature Review and Theoretical Assumption

2.1. Literature Review

Digital financial inclusion has developed on the basis of traditional financial inclusion, and although scholars have different interpretations of the connotation of digital financial inclusion, the core interpretation is inseparable from the two keywords of digital technology and finance. As for the measurement of digital financial inclusion, the Peking University Digital Financial Inclusion Index has been used in most of the studies on digital financial inclusion, which is relatively systematic, comprehensive, representative and representative. In terms of the impact of digital financial inclusion, scholars mainly focus on the following aspects: the impact of digital financial inclusion on economic growth; the impact of digital financial inclusion on traditional finance; the impact of digital financial inclusion on residents' income and consumption; and the impact of digital financial inclusion on corporate innovation. Under the policy orientation of green development, there are few studies on the impact of digital inclusive finance on green innovation.

Researches on green innovation mainly focus on the analysis of spatial patterns obtained through the evaluation of the results of green innovation, the influencing factors of green innovation and the analysis of the impact of green innovation. For the measurement of green innovation, there is no harmonized system of the indicator in the current study. For the overall evaluation of green innovation, most of the scholars, though adopting different methods, put forward the index system from the three aspects of green innovation inputs, green innovation outputs and green innovation environment; for the efficiency measurement of green innovation, scholars mostly use the DEA and its extended models, such as the DEA-RAM, the DEA-SBM, and the DEA-Malmquist, etc., to measure. In terms of factors affecting green innovation, scholars mainly focus on the following aspects: the impact of

environmental regulation on green innovation, the impact of innovation inputs (e.g., government subsidies, foreign direct investment, etc.) on green innovation, the impact of public policy on green innovation, and few scholars study the impact of digital financial inclusion on green innovation.

Based on this, this paper takes the Yangtze River Delta region as an example to study the impact of digital inclusive finance on the level of regional green innovation.

2.2. Theoretical Assumption

The high-risk and high-investment characteristics of green innovation determine the insufficiency of government financial support and enterprise free funds, and the advantages of digital inclusive finance, such as wide coverage, low cost and low threshold, well meet the financial needs of green innovation. On the one hand, the universality of digital inclusive finance well alleviates the financing constraints of innovative enterprises, especially small and medium-sized innovative enterprises, in carrying out green innovation; on the other hand, digital inclusive finance relies on digital technologies, such as big data, cloud computing and artificial intelligence, which have unparalleled advantages in data processing and analysis, and prevents innovation through the application in the fields of risk rating, investment matching, dynamic pricing and intelligent decision-making, and so on. risk and improve the security of innovation capital. Therefore, this paper believes that digital inclusive finance can stimulate the innovation vitality of enterprises and enhance the level of green innovation in the region.

Accordingly, it is hypothesized that the development of digital inclusive finance can effectively promote the improvement of regional green innovation level.

3. Study Design and Descriptive Analysis

3.1. Variables and Data

3.1.1. Dependent Variable

The dependent variable of this study is the green innovation index. Current research does not have a more unified index system or empirical methodology for the measurement of green innovation, but it is generally agreed that green innovation should reflect both innovativeness and the concept of sustainable development, and that it needs to be combined with the environment and its economic and social benefits [6].As the examination of green innovation in this study tends to be the result rather than only its process or efficiency, and combined with the accessibility of data, this paper mainly draws on the entropy weight method adopted by Fu Zhao et al. (2016) to measure the green innovation index from the three perspectives of green innovation inputs, green innovation outputs, and the green innovation environment, and on this basis, slightly modified, the specific index system is shown in Table 1 below.

Among them, innovation inputs are divided into capital inputs and human inputs, with capital inputs including R&D capital represented by the indicator of the share of R&D internal expenditure in GDP and introduced capital represented by the expenditure on the introduction of technology by industrial enterprises above large-scale, and human inputs choosing the indicator of the full-time equivalent of R&D personnel. The output of green innovation includes both the output of traditional innovation activities and the environmental benefits of green innovation. In this paper, two indicators are chosen for traditional innovation output, namely the number of authorized patent applications and technology market turnover, and three indicators are chosen for environmental benefits of green innovation, namely energy consumption per unit of GDP, wastewater emissions and industrial solid waste generation. The innovation environment considers the government's environmental regulation and selects three indicators: energy saving and environmental protection expenditures, total investment in environmental pollution control, and resource tax in each province.

Table 1. Green Innovation Index

Dependent variable	Primary indicator	Secondary indicators
Green Innovation Index	Green Innovation Inputs	Share of R&D internal expenditure in GDP
		Expenditures on the introduction of technology by industrial enterprises above large-scale
		Full-time equivalent of R&D personnel
	Green Innovation Outputs	Number of authorized patent applications
		Technology market turnover
		Energy consumption per unit of GDP
		Wastewater emissions
		Industrial solid waste generation
	Green Innovation Environment	Energy saving and environmental protection expenditures
		Total investment in environmental pollution control
		resource tax

3.1.2. Independent Variable

The independent variable of this study is the digital financial inclusion index. Referring to the practice of most scholars, this paper adopts the Digital Financial Inclusion Index released by the Digital Finance Research Center of Peking University to express it.

In this index system, the digital financial inclusion index includes the breadth of coverage, the depth of use and the degree of digital support services, and in the empirical part of this paper, the breadth of coverage and the depth of use will also be chosen to be regressed separately, to verify the impact of the sub-dimensions of digital financial inclusion on the green innovation respectively.

This paper is about the digital financial inclusion in the Yangtze River Delta region between 2011 and 2020, and the data source is the relevant data released by the China Digital Finance Research Center of Peking University between 2011 and 2020.

3.1.3. Control Variables

In addition to the existence of the impact of the level of digital financial development on green innovation, other factors may also have an impact on the degree of green innovation in each province, and if they are omitted, they are likely to bias the estimation results. Based on this, it is necessary to control for this part of the factors before conducting the regression estimation.

Drawing on current research, industrial structure and labor quality are chosen as the control variables in this paper. In this paper, the sum of the added value of the second and third industries as a share of GDP is used to measure the industrial structure, and the number of students enrolled in tertiary institutions per 100,000 people is used to measure the quality of laborers, which is used to analyze the development of green innovation in more provinces. The source of data is the China Statistical Yearbook from 2012 to 2021.

3.2. Descriptive Analysis

In order to visualize more intuitively the development of digital financial inclusion as well as the various indicators of green innovation in the YRD region over a ten-year period and to make preliminary judgments about the relevance, this paper first plots the ten-year data in figures as follows.

Figure 1 shows the changes in the degree of green innovation of the four provinces in the Yangtze River Delta region from 2011 to 2020. As can be seen from the figure, except for Anhui Province, the green innovation of the other three provinces shows an upward trend over the ten years, and there is a clear and stable gap between the four provinces, with Shanghai having the highest green innovation index value, Zhejiang the next highest, Jiangsu the next, and Anhui the lowest index value. In the YRD region, Shanghai has the highest degree of green innovation in the last ten years, while Anhui province has the lowest degree of green innovation.

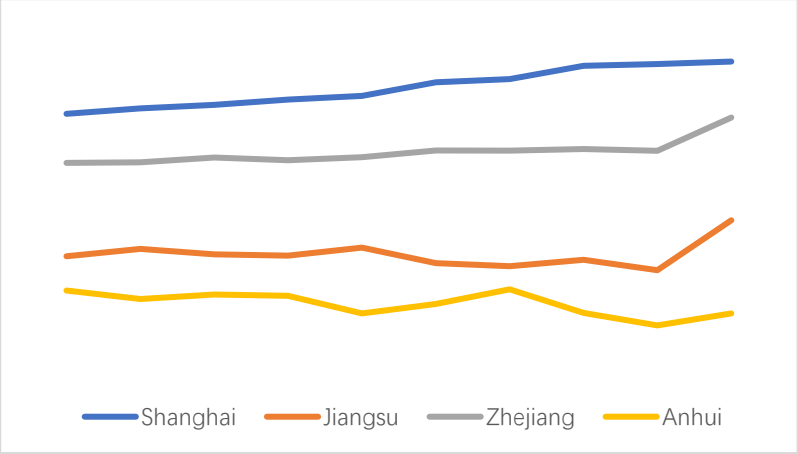


Figure 1. Green Innovation Index of Yangtze River Delta, 2011-2020

Figure 2 shows the changes in the green digital financial inclusion index of the four provinces in the Yangtze River Delta region from 2011 to 2020. As can be seen from the figure, the four provinces in the Yangtze River Delta region have shown a steady upward trend in digital financial inclusion over the decade, and there is a certain gap in the development among the four provinces, with Shanghai having the highest value of the index, followed by the corresponding index of Zhejiang Province, and the lowest in Anhui Province. The performance of digital financial inclusion among the provinces follows the same trend as the development of the green innovation index.

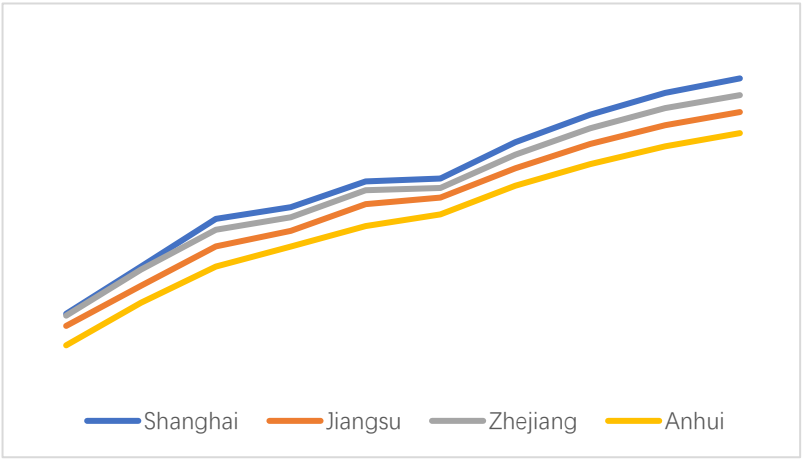


Figure 2. Digital Financial Inclusion Development in Yangtze River Delta, 2011-2020

Figures 3 and 4 show the development of the two sub-dimensions of the breadth of coverage and depth of use of the green digital financial inclusion index for the four provinces in the Yangtze River Delta region from 2011 to 2020, respectively. As can be seen from the figure, the breadth of coverage and depth of use of digital finance in the four provinces in the Yangtze River Delta region have shown an upward trend over the ten-year period, and the ranking of the indexes among the provinces is consistent with the total digital finance index as well as the green innovation index, with the highest in Shanghai and the lowest in Anhui Province. Comparing the two sub-dimensions, the growth trend of digital finance coverage breadth is more stable, while the depth of use shows a fluctuating upward trend.

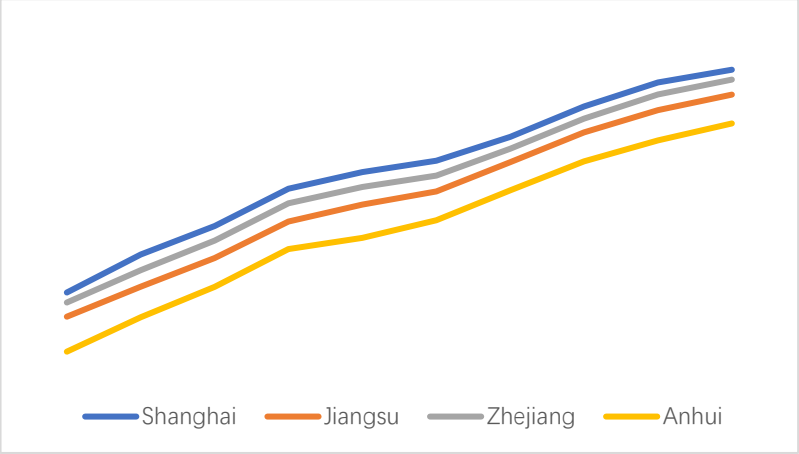


Figure 3. Breadth of Digital Financial Inclusion Coverage in Yangtze River Delta, 2011-2020

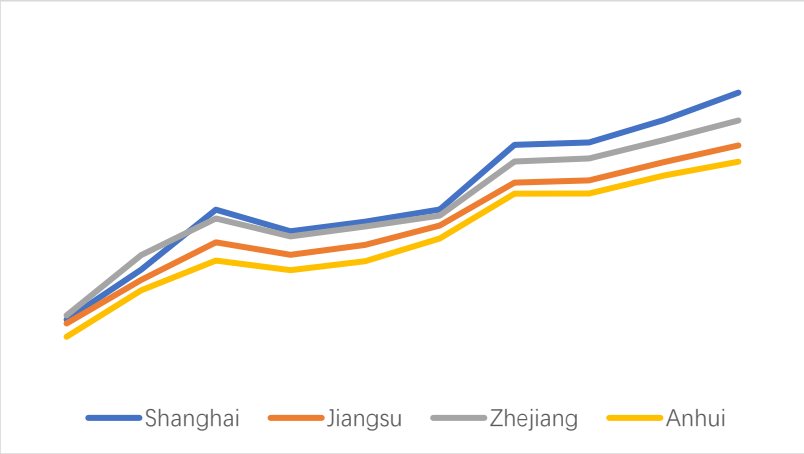


Figure 4. Depth of Digital Financial Inclusion Usage in Yangtze River Delta, 2011-2020

4. Empirical Analysis

4.1. Model Construction

Based on the definition above, the model is set up in this paper as follows:

$$gi_{i,t} = c + \beta_1 x_{i,t} + \beta_2 indus_{i,t} + \beta_3 hr_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where the dependent variable $gi_{i,t}$ is the green innovation index of province i in year t, calculated using the entropy weight method. The independent variable $x_{i,t}$ is the digital financial inclusion index of province i in year t, which is regressed using the total digital financial inclusion index (x), the subdimension breadth of digital financial inclusion coverage (x_1), and the subdimension depth of digital financial inclusion usage (x_2), respectively. The control variables are $indus_{i,t}$ and $hr_{i,t}$, which denote the industrial structure and labor quality of province i in year t, respectively.$\varepsilon_{i,t}$ denotes the random error term.

4.2. Model Diagnosis

4.2.1. Unit Root Test

The unit root test is used to test whether the series is stationary or not, if there is a unit root, there may be pseudo-regression in the regression analysis. Therefore, before regression, this paper first unit root test for each variable. The results are displayed in Table 2 below.

Table 2. Unit Root Test

Variable	p value (LLC Test)	p value (ADF Test)	Stationarity
gi	0.0003	0.0435	Yes
x	0.0002	0.0332	Yes
x_1	0.0000	0.0196	Yes
x_2	0.0000	0.0477	Yes
indus	0.0003	0.0260	Yes
hr	0.0001	0.0027	Yes

From the results, it can be seen that the variables are stationary after first-order or second-order differencing, so there is no need for cointegration test, and the F-test can be performed directly.

4.2.2. F-test and Hausman Test

Since this study uses panel data, an F-test is needed to determine whether there are individual effects in the model, that is, to determine whether a mixed estimation model should be chosen for estimation or a fixed effects model. Since it is important to determine the reasonableness of including control variables, in each regression this study performs separate tests with the inclusion of control variables as well as without control variables. The F-statistic is calculated through the sum of squares of the residuals from the regression equation using the following equation.

$$F = \frac{(SSE_r - SSE_f)/(N-1)}{SSE_f/(NT-N-K)} \sim F(N-1, NT-N-K) \quad (2)$$

Where SSE_r is the residual sum of squares for the mixed estimation model and SSE_f is the residual sum of squares for the fixed effects model. N is the number of cross-sections, which in this study is the number of provinces 4, and T is the number of time series, which in this paper is 10. K is the number of explanatory variables, which in this paper is 1 when control variables are not included and 3 when they are included.

After calculating the results according to the formula and checking the table to compare with $F(N-1, NT-N-K)$, if the calculated F value is greater than the value of the table, the original hypothesis is rejected and the fixed effect model is used. The calculated F-statistic values and the selected model are shown in Table 3 below.

The results of the F-test indicate that the regression models all have individual effects, and further consideration needs to be given to whether the individual effects of the models are correlated with the explanatory variables. The correlation test can be performed by Hausman test by observing the obtained p-value, if it is less than 0.05 then the original hypothesis is rejected and the fixed effect model is selected. The results of Hausman test are also shown in table 3 below.

Table 3. F-test and Hausman Test

Independent Variable	Control Variable	F-statistic	Hausman Test	Model
x	No	448.99	Reject H_0	Fixed Effect Model
	Yes	486.67	Reject H_0	Fixed Effect Model
x_1	No	1278.44	Reject H_0	Fixed Effect Model
	Yes	506.16	Reject H_0	Fixed Effect Model
x_2	No	1365.69	Reject H_0	Fixed Effect Model
	Yes	508.25	Reject H_0	Fixed Effect Model

4.3. Regression Results

Firstly, a fixed effect model was used to regress the total indicators of digital financial inclusion to observe the impact of the overall development of digital financial inclusion on green innovation. The results are organized in Table 4 below.

From the regression results, it can be concluded that in the Yangtze River Delta, the total digital financial inclusion index has a significant positive impact on the green innovation situation in the region. With the addition of control variables, the model's goodness of fit is even better, the impact of digital financial inclusion on the green innovation index is significantly positive at the 1% level, and the green innovation index significantly increases by 0.4614 for every 1 unit increase in digital financial inclusion, the higher the level of regional digital financial inclusion, the higher the degree of green innovation in the region.

Table 4. Digital Financial Inclusion Regression Results

Variables	(1)	(2)
x	0.1759**	0.4614***
	(0.0711)	(0.0868)
Control Variable	No	Yes
Adjusted R-square	0.9742	0.9864
N	160	160

Note: Standard error is shown in parentheses. *, **, *** indicate significant at 10%, 5%, and 1% significant levels, respectively.

In addition, the same fixed-effects model was used to regress the two sub-dimensions of digital financial inclusion to test the impact of the breadth of coverage and depth of use of digital financial inclusion on green innovation in the Yangtze River Delta, respectively. The results are organized in Table 5 below.

Table 5. Sub-dimensions Regression Results

Variables	(1)	(2)	(3)	(4)
x_1	0.1774***	0.5548***		
	(0.0771)	(0.0990)		
x_2			0.1935***	0.4317***
			(0.0686)	(0.0795)
Control Variable	No	Yes	No	Yes
Adjusted R-square	0.9737	0.9870	0.9753	0.9866
N	160	160	160	160

Note: Standard error is shown in parentheses. *, **, *** indicate significant at 10%, 5%, and 1% significant levels, respectively.

From the regression results, it is easy to conclude that both sub-dimensions of digital financial inclusion have a significant positive effect on the green innovation development index at the 1% level. Moreover, the model fits better with the addition of control variables, both in terms of breadth of coverage and depth of use. At the same time, the degree of influence of each sub-dimension and the total index is not much different, the green innovation index increases by 0.5548 for each unit increase in the breadth of coverage of digital financial inclusion, and the green innovation index increases by 0.4317 for each unit increase in the depth of use of digital financial inclusion. The increase in the breadth of coverage and the depth of use of digital financial inclusion in a region significantly increases the degree of green innovation in that region.

5. Conclusion

By establishing an empirical model, this paper tests and analyzes the impact of digital financial inclusion on green innovation in the Yangtze River Delta through Eviews software, which provides theoretical guidance for the problem of innovation difficulties in the YRD region due to financing difficulties. The study found that the degree of digital inclusive finance and green innovation in all provinces and cities in the Yangtze River Delta region basically showed an upward trend between 2011 and 2020. In terms of the degree of development, both indicators are optimal in Shanghai,

followed by Zhejiang and ranked last in Anhui. In addition, the empirical results show that the development of digital inclusive finance can effectively promote green innovation, and both its breadth-of-coverage sub-dimension and depth-of-use sub-dimension have similar results with little difference in the degree of influence.

Based on the findings of the study, this paper argues that the development of digital inclusive finance should be continuously encouraged to expand the breadth of coverage and depth of use of digital inclusive financial services, reduce the competitive disadvantages of enterprises in disadvantaged areas such as Anhui Province, and promote the integrated development of the Yangtze River Delta. Enterprises can be guided at the policy level to establish an awareness of green innovation, create key digital financial products, integrate green innovation resources, create a low-cost, convenient and efficient comprehensive service platform for green innovation by means of convenient and efficient digital financial services, and actively support high-technology enterprises as well as some specialized small and medium-sized enterprises to participate in the development of green innovation.

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