Threshold Effect of Digital Inclusive Finance on Carbon Emissions in The Yangtze Delta Region

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Abstract

The Yangtze River Delta (YRD) region is a demonstration area for the development of digital inclusive finance and a pilot field for achieving the "double carbon" target. However, does digital inclusive finance in the Yangtze River Delta region promote carbon emission reduction? In this paper, we use a threshold effect model to explore the impact of digital inclusive finance on per capita carbon dioxide emissions in 41 prefecture-level cities in the Yangtze River Delta region from 2014 to 2019. The results show that the development of digital inclusive finance in the Yangtze River Delta region positively affects the per capita carbon dioxide emissions of local cities. There is a non-linear relationship between the development of digital inclusive finance and carbon emissions, and there is a significant single threshold effect. Therefore, it is suggested that the Yangtze River Delta region should deepen the cooperation between digital inclusive finance policies and carbon emission reduction in the Yangtze River Delta, make reasonable use of regional advantages, and build cross-city green technology mutual assistance. It also expands the scope of "green monitoring" and releases targeted green financial products for small and medium-sized enterprises

Keywords: *digital inclusive finance; urban carbon emission reduction; Yangtze River Delta region; threshold effect*

1. Introduction

Since the 21st century, China's economy has continued to grow rapidly, but it has also become the world's largest carbon emitter. Based on the inherent requirement of promoting sustainable development and the responsibility of building a community of human destiny, China made its first commitment to peak CO2 emissions around 2030 in the "U.S.-China Joint Statement on Climate Change" at the end of 2014.In 2020, a "double carbon" target vision was announced, that is, to achieve carbon peak by 2030 and carbon neutrality by 2060. However, China has a vast territory, and the natural resource endowment and economic development level of each province vary, so China has a tight time frame, large scope and many difficulties to achieve the "double carbon" target. Therefore, regional early and pilot implementation will be an important driver for China to achieve the "double carbon" target. The Yangtze River Delta region, which has the economic foundation, technical capability and demand for energy saving and emission reduction, takes the lead in energy transformation and deep decarbonization, and undertakes the strategic mission of opening up the road to zero

carbon development in the region. In recent years, the top-level design of the construction of the green Yangtze River Delta has been enhanced, and has covered 18 national low-carbon pilot cities such as Shanghai, Hangzhou and Nanjing, providing constructive advice to other regions in China to avoid or take fewer detours on the way to accomplish the peak target. At the same time, digital inclusive finance, which relies on innovative technologies such as intelligent algorithms, big data and cloud computing, has penetrated into all aspects of life and production, and is of great significance to ensure that China achieves the "double carbon goal". Especially in the Yangtze River Delta city cluster, which has a high overall level, the municipal districts of Hangzhou and Shanghai basically monopolize the top 20 in the ranking of digital inclusive finance in the county. In this context, the relationship between regional digital inclusive finance and regional carbon emissions deserves in-depth study. Therefore, based on the Yangtze River Delta Integration Demonstration Zone, we will investigate whether the development of digital inclusive finance has an impact on the carbon emissions in the region. If so, is the relationship linear? If the relationship is non-linear, where is the inflection point of the role of digital inclusive

finance? How should the Yangtze River Delta region combine the development of digital inclusive finance and the promotion of carbon emission reduction? The exploration of the above questions is important for China to achieve the goal of "carbon peak and carbon neutrality" and successfully complete this extensive and profound green industrial revolution.

2.Related Work

At present, academics have paid extensive attention to the impact of digital inclusive finance on carbon emission reduction, and two main views exist. One believes that the development of digital inclusive finance is beneficial to the achievement of carbon emission reduction targets. For example, Guo Guixia et al [1] found that digital inclusive finance plays a significant positive role in carbon emission reduction of regions and enterprises through two indirect ways: promoting the industrialization of digital technology and digital empowerment of industries based on a panel of prefecture-level cities and a large micro data set of enterprises. Meanwhile, there is a significant spatial heterogeneity in the ameliorating effect of digital finance development on urban carbon emissions, with a stronger effect in the eastern region and a greater impact on regions located within urban agglomerations [2]. Second, some scholars have also proposed the negative effect of digital inclusive finance on carbon emission reduction. Earlier, Grossman and Krueger (1995) suggested an inverse u-shaped relationship between economic growth and carbon emissions and proposed the environmental Kuznets curve (EKC) hypothesis. In recent years, some scholars have tested it in China. For example, Chen found that the financial inclusion effect showed a negative effect during 1996-2001 by quantifying regional financial inclusion and carbon emissions through an empirical review [3]. Chi-Min Peng et al [4] found an inverted U-shaped relationship between financial scale and carbon emissions in the eastern region based on a study of the Yangtze River Economic Zone. Therefore, is the impact of digital inclusive finance, a new form of inclusive finance, on carbon emissions a facilitator or a hindrance? Is there a nonlinear relationship between the two?

Domestic and foreign scholars have different views on the impact path of digital inclusive finance on carbon emissions. In this paper, we summarize the views of scholars, and the impact of digital inclusive finance on carbon emissions is mainly direct and indirect. The direct impact is demonstrated by the fact that digital inclusive finance reduces carbon emissions by lowering the threshold of financial services, improving the efficiency of financial services, compensating for the availability of corporate financing and reducing the cost of corporate financing [5]. Digital inclusive finance is innovatively integrated with traditional service industries outside the financial sector to give full play to its special efficacy of convenient services. A series of innovative online platforms in the daily field such as online registration, online payment of living expenses, and Ant Forest low-carbon travel effectively reduce consumers' offline carbon emissions [6]. At the same time, it has also been suggested that digital inclusive finance brings lower costs of business expansion [7] and consumer consumption convenience, thus expanding the production scale of manufacturing and the demand for energy-intensive machines [8] and generating more CO2. The indirect impact of digital inclusive finance on carbon emissions through can be interpreted from the perspective of expanding scale effect, promoting industrial upgrading, and accelerating industrial structure change, and the specific impact paths are as follows. First, digital inclusive finance relies on digital advantages to accelerate economic growth, and the demand for production factors is increasing, and carbon emissions are also increasing. The scale effect is generated, which leads to the increase of carbon emissions at the early stage of development until it reaches the scale crossing point, and digital inclusive finance will gradually have a positive effect on carbon emission reduction. Second, digital inclusive finance promotes industrial transformation and upgrading through digital empowerment of industry, improves the breadth and efficiency of the service real economy, and thus promotes carbon emission reduction. At the same time, the improvement of industrial efficiency and breadth of service industry reverse to stimulate economic development, expand social demand and production scale, and inhibit carbon emission reduction [9]. Third, digital inclusive finance accelerates the development of carbon trading and raises the green production requirements of enterprises, requiring them to accelerate the development of tertiary industries, promote the rationalization of industrial structure, and reduce carbon dioxide emissions [10]. The normalization of green policies and the marketization of carbon emissions have forced a large number of high-polluting enterprises to vigorously develop advanced production capacity, but at the same time, a large number of enterprises have moved to neighboring cities, which, for urban clusters, even leads to spatial spillover of carbon emissions [11].

As a model economic region, the Yangtze River Delta region has a high overall level of financial inclusion, with most indicators maintaining a growth trend.The Yangtze River Delta region plays an exemplary role in the national city cluster by taking advantage of its unique geographical location in the basin. Since the birth of the concept of digital inclusive finance, the Yangtze River Delta region has been actively exploring the path of digital economy to empower the real economy, creating a demonstration area for the industrialization of digital economy in the form of "Internet+", which has become a new driving force and new advantage for regional economic growth. In terms of industrial sectors, industries with large carbon emissions in China are

concentrated in urban areas, and mainly in the lower eastern coastal areas of rivers and streams where 40% of China's population and 60% of GDP are concentrated. And an obvious aggregation effect has been formed with large cities such as Shanghai, Nanjing, Suzhou, Changzhou, Hefei and Hangzhou as the core high-emission gathering areas. Therefore, the carbon emission reduction strategy in the Yangtze River Delta region based on the perspective of digital inclusive finance in order to explore a new development path that is complementary to the construction of ecological civilization and economic and social development has important research significance.

In summary, the relationship between both digital inclusive finance and carbon emissions remains unclear and there is a controversial linear and non-linear relationship. Based on this, this paper selects the panel data of 41 prefecture-level cities in the Yangtze River Delta region from 2014-2019 as a demonstration area of zero-carbon development with high-quality development and leading level of digital inclusive finance. We use a panel data threshold model with digital inclusive finance as the threshold variable to examine whether there is a nonlinear relationship between digital inclusive finance development and carbon emission reduction in the Yangtze River Delta region.

The possible innovations of this paper are as follows. One, the threshold model is used to examine the nonlinear relationship between digital inclusive finance on carbon emission reduction in the perspective of the Yangtze River Delta region, which provides an error reference for static linear analysis. Second, focusing on the degree of digital inclusive finance development and carbon emission reduction progress in China's urban agglomerations, the two are included in the same analytical framework to help carbon emission reduction strategies with a regional first perspective.

3. Model Construction and Study Description

3.1. Model Construction and Estimation Methodology

Considering the possible non-linear relationship between digital inclusive finance and carbon emissions, the non-dynamic panel threshold model proposed by Hansen (1999) and the estimation method are adopted in the following. The threshold model does not require a specific form of nonlinear model to test whether there is no threshold between digital inclusive finance and carbon emissions, whether there is a significant nonlinear relationship, and the number of thresholds, so that the nonlinear relationship between digital inclusive finance and carbon emissions can be portrayed more clearly.

In this paper, the panel data of 41 prefecture-level cities in the Yangtze Delta region from 2014-2019 are

selected for testing, and the model is set up as follows by drawing on the existing literature that uses panel models for research.

$$PCO_{2_{it}} = \beta_0 + \beta_1 DFII_{it} \times I(\omega_{it} \leq \gamma) \\ + \beta_2 DFII_{it} \times I(\omega_{it} \geq \gamma) + \beta_3 X_{it} \\ + \mu_{it} + \varepsilon_{it}$$

$$(1)$$

Among them, $PCO_{2_{it}}$ (carbon dioxide) is the explanatory variable, representing the per capita carbon dioxide emissions (tons per person) in year i in prefecture-level city t ; $DFII_{it}$ (Digital Financial Inclusion Index) is the core explanatory variable, measuring the development level of digital financial inclusion in year i in prefecture-level city t; $I(\ )$ is the demonstrative function, ω is the threshold variable, γ is the threshold value to be estimated threshold value; X is a series of control variables, including urbanization rate, fiscal expenditure, openness to the outside world, financial development level, greening coverage, foreign direct investment, road area, and residents' consumption ability; μ is an individual fixed effect; and ε is a random disturbance term.

3.2. Variable selection and data sources

The statistical indicators of 41 cities in the Yangtze River Delta region (Shanghai, Jiangsu, Zhejiang and Anhui) from 2014 to 2019 were selected. The data are mainly obtained from the "China City Statistical Yearbook (2015-2020)", the statistical yearbooks of each province and the annual national economic and social development statistical bulletins of each city.

3.2.1. Explanatory variables

The existing measures of carbon emissions include carbon emissions and carbon intensity. Given that the measure of China's "double carbon" target is total carbon emission, and carbon emission is largely related to population density, therefore, this paper adopts per capita carbon emission (tons/person) as the explanatory variable.

3.2.2. Threshold variables

This paper uses the Peking University Digital Inclusive Finance Index (2011-2020), compiled by the Digital Finance Research Center of Peking University in April 2021, as the threshold variable to measure the degree of digital inclusive finance development in each city. The index involves three sub-dimensions, which are breadth of coverage (Cover), depth of use (Depth) and digitization (Dig) [12].

3.2.3. Control variables

Since the omission of control variables can have an impact on the estimation error of parameters, the relevant

control variables are selected in this paper with full reference to existing studies as follows:

a) urbanization rate (URBAN), expressed as the proportion of urban resident population to year-end resident population in each region.

b) Government expenditure (GOV), which is expressed as the share of budgetary expenditure in the GNP of each region.

c) Openness to the outside world (OPEN), expressed as a share of total exports in the region's GNP

d) Financial development level (FIN), expressed as a proportion of the total RMB deposits and loans of financial institutions to the region's GDP.

e) Green Ratio (GR), expressed using the proportion of greening coverage area to administrative area.

f) Foreign Direct Investment (FDI), expressed using the proportion of industrial output value completed by industrial enterprises above the scale to the regional GDP.

g) Road space (RS), expressed as the proportion of road space to administrative area.

h) Consumer ability (CA), expressed as the proportion of total retail sales of consumer goods to regional GDP.

The descriptive statistics of the variables are shown in Table 1.

Table 1 Definition of variables and their descriptive statistics

Variable type	Variable name	Unit	Sample size	Mean	Standard deviation	Minimum	Maximum
Dependent variable	PCO_2	ton/person	246	2.041	1.453	0.249	6.533
Explanatory variables	$DFII$	Index	246	2.218	0.426	1.249	3.216
	Cover	Index	246	2.107	0.413	1.216	3.104
	Depth	Index	246	2.266	0.507	1.133	3.319
	Dig	Index	246	2.499	0.492	1.372	4.379
Control variables	$URBAN$	%	246	0.515	0.185	0.005	0.899
	GOV	%	246	0.167	0.060	0.081	0.355
	OPEN	%	246	0.176	0.1772	0.016	0.883
	FIN	%	246	2.676	0.900	1.128	6.255
	ER	%	246	0.420	0.041	0.296	0.607
	FDI	%	246	0.024	0.017	0.002	0.096
	RS	%	246	3.511	3.107	0.403	14.660
	CA	%	246	0.422	0.092	0.243	0.660

In order to prevent serious multicollinearity of the variables, correlation tests were performed on the variables. As shown in Table 2, the test results indicate that the correlation coefficients between the explanatory variables and the control variables are all small and there is no serious multicollinearity. Moreover, the digital financial inclusion index and its sub-dimensions digital

financial coverage breadth index and digital financial use depth index are significantly and positively correlated with per capita carbon emissions. It can be tentatively confirmed that the impact of digital inclusive finance on carbon emissions in the Yangtze River Delta region is positive.

Table 2 Correlation test of variables

Variables	(PCO2)	(index)	(Cover)	(Depth)	(Dig)	(URBAN)	(GOV)	(OPEN)	(ER)	(FIN)	(RS)	(FDI)	(CA)
PCO2	1.000												
index	0.324***	1.000											
Cove	0.418***	0.964***	1.000										
Depth	0.252***	0.961***	0.879***	1.000									
Dig	0.079	0.820***	0.681***	0.775***	1.000								
URBAN	0.541***	0.380***	0.473***	0.280***	0.176***	1.000							
GOV	-0.485***	-0.255***	-0.377***	-0.166***	0.006	-0.484***	1.000						
OPEN	0.326***	0.248***	0.370***	0.199***	-0.087	0.171***	-0.331***	1.000					
ER	0.034	0.147**	0.179***	0.105*	0.088	0.281***	-0.231***	-0.057	1.000				
FIN	0.375***	0.376***	0.432***	0.352***	0.130**	0.182***	-0.010	0.451***	-0.033	1.000			
RS	-0.458***	-0.318***	-0.404***	-0.240***	-0.113*	-0.492***	0.626***	-0.392***	0.052	-0.194***	1.000		
FDI	0.168***	-0.105*	-0.143**	-0.088	0.006	-0.058	0.006	-0.155**	-0.078	-0.060	-0.098	1.000	
CA	-0.369***	0.042	-0.009	0.095	0.071	-0.394***	0.356***	0.074	0.090	0.259***	0.113*	-0.122*	1.000

Note: ***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

4.Empirical Results and Analysis

To explore the nonlinear relationship between digital inclusive finance and carbon emissions, this paper uses a threshold model for empirical analysis, with annual per capita carbon emissions (tons per person) in each city as the explanatory variable and the Digital Inclusive Finance Index (DFII) as the core explanatory variable. At the same time, the digital inclusive finance index itself is selected as the threshold variable. The results of the threshold effect test for both are shown in Table 3. The single threshold of digital inclusive finance and carbon emission per capita is significant at the 1% statistical level with a threshold value of 1.7502, but the p-value of the double threshold does not pass the significance test. Thus, it is concluded that there is only a single threshold effect on digital inclusive finance development degree and carbon emission per capita in the Yangtze River Delta. This indicates that there is a non-linear relationship between the degree of digital inclusive finance development and carbon emissions per capita in the Yangtze River Delta, and the relationship between the digital inclusive finance threshold estimator and the likelihood ratio statistic is shown in Fig. 1.

Table 3 Test results of the threshold effect of the degree of development of digital inclusive finance (regardless of dimension) on per capita carbon emissions

Number of thresholds	Threshold test					
	P-value	Threshold	95% confidence	1% critical value	5% critical value	10% critical value
Single threshold	0.000	1.7502***	[1.7270,1.7535]	15.760	13.251	10.942
Double threshold	0.460	1.6880	[1.6770,1.7148]	25.586	17.763	15.728
		1.7270	[1.6441,1.7394]			

Note: ***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.
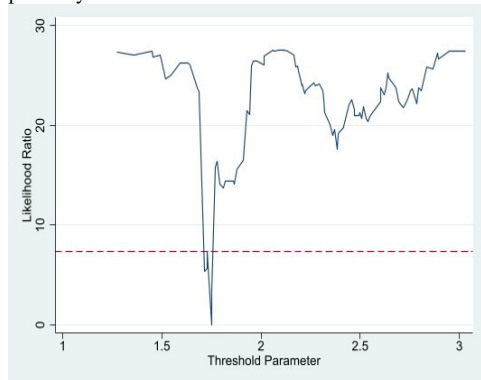

Fig.1 Single threshold estimator and likelihood ratio

In addition, this paper compares the estimation results of the relationship between digital inclusive finance development and carbon emissions using three linear models with the fixed-effects model, random-effects model and mixed regression model with the threshold model nonlinear model. The estimation results of the three linear models are shown in columns (1) to (3) of Table 4, and the estimation results of the panel threshold model are shown in column (4) of Table 4.

According to the estimation results of linear regression and non-linear regression, the regression coefficients of digital inclusive finance development on carbon emissions per capita in the Yangtze River Delta region are both positive, showing a significant positive effect, but it does not mean that there is a strict linear relationship between the two. According to the results of the threshold effect, the positive effect of digital inclusive finance development on per capita carbon emissions in the Yangtze River Delta region shows a trend from strong to weak, and there is a significant single threshold between the two, i.e., there is a significant non-linear relationship. Specifically, when the digital inclusive finance index is less than the threshold value of 1.7502, the effect of digital inclusive finance on per capita carbon emissions in the YRD region is positive and significant at the 1% significance level. When the threshold value of digital inclusive finance index is 1.7502, the impact of digital inclusive finance index on carbon emission per capita in YRD region is still positive and significant at 1% significance level, but its impact coefficient decreases. It means that when digital inclusive finance is at a low level (index≤1.7502), its positive effect on per capita carbon emissions is more obvious and significant for the YRD region. When digital financial inclusion reaches a high level (index > 1.7502), the positive effect on per capita carbon emissions is significantly weaker. A reasonable explanation for this phenomenon in the Yangtze River Delta region is that when the development level of digital inclusive finance is low, the rapid emergence of digital inclusive finance significantly improves the economic level of the Yangtze River Delta region. A series of economic activities such as introducing advanced technology, increasing employment opportunities, and building infrastructure will attract the migration of enterprises and population movement, and the rapid expansion of production capacity will lead to a sharp increase in energy demand, which in turn will increase energy demand and CO_2 emissions. This has a positive effect on regional per capita carbon emissions. As digital inclusive finance in the Yangtze River Delta region enters a white-hot stage, the cross-regional joint prevention and control mechanism continues to improve, and a large number of green financial policies, institutions and products emerge. The positive effect of digital inclusive finance on regional per capita carbon emissions is significantly weakened and the carbon emission reduction effect is enhanced as digital inclusive finance exerts its green benefits.

Table 4 Regression results of the relationship between digital inclusive finance development (regardless of dimension) and carbon emissions per capita

Explanatory variables	(1) Two-way fixed effects regression	(2) Random effects regression	(3) Mixed effects regression	(4) Return of the threshold effect
index	1.192**	1.418**	0.175	
index_0 (index≤1.7502)				0.481***
index_1 (index > 1.7502)				0.315***

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

As the digital finance index used in this paper contains 3 sub-dimensions of breadth of coverage, depth of use and digitization. In order to further analyze which dimensions of digital finance affect the regional per capita carbon emissions, we estimate the threshold models for them separately, and the results are shown in Table 5. The results show that all three indicators have a significant single threshold effect with regional per capita carbon emissions, a non-linear relationship, and a significant increasing effect on regional per capita carbon emissions. However, the positive effect slows down significantly after reaching the post-threshold value, which is conducive to promoting carbon emission reduction.

Table 5 Results of the threshold effect of digital inclusive financial development (three dimensions) and per capita carbon emissions

Variables	Cover	Depth	Dig
Threshold effect	Yes	Yes	Yes
Threshold	1.807**	1.5661***	2.1602***
Cover(Cover≤1.8079)	0.510***		
Cover(Cover>1.8079)	0.393***		
Depth(Depth≤1.5644)		0.351***	
Depth(Depth>1.5644)		0.158***	
Dig(Dig≤1.8079)			0.402**
Dig(Dig>1.8079)			0.238**

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

5.Heterogeneity analysis test

Since there is significant regional heterogeneity in the level of development of digital inclusive finance and carbon emissions in different regions of the Yangtze River Delta. Therefore, there may also be regional heterogeneity in the impact of the development of digital inclusive finance on per capita carbon emissions. In order to consider regional heterogeneity, this paper refers to the approach of Liu, Ruiming, and others [7], and classifies provincial capitals, sub-provincial cities, and "larger cities" as high-grade cities, including Shanghai, Nanjing, Wuxi, Suzhou, Hangzhou, and Ningbo. The others are general cities. According to the test results in Table 6, digital inclusive finance has a significant positive effect on per capita carbon emissions in the Yangtze River Delta region, both in high-ranking cities and general cities, and it is significant at the 1% level. However, the positive effect decreases significantly when digital inclusive finance develops to a certain level, and the conclusion still holds.

Table 6 Heterogeneity analysis results

	High-grade cities				General-grade cities			
	index	Cover	Depth	Dig	index	Cover	Depth	Dig
index_0 (index≤1.7502)	0.436**				0.463***			
index_1 (index > 1.7502)	0.303*				0.275***			
Cover (Cover≤1.8079)		0.138				0.474***		
Cover (Cover > 1.8079)		0.181				0.352***		
Depth (Depth≤1.5644)			0.168**				0.304***	
Depth (Depth > 1.5644)			0.067				0.111	
Dig (Dig≤1.8079)				0.042*				0.391***
Dig (Dig > 1.8079)				-0.001				0.193**

6.Conclusions

Based on the panel data of prefecture-level cities in the Yangtze River Delta region from 2014 to 2019, this paper empirically investigates the relationship between digital inclusive finance and regional carbon emissions using a threshold model, and draws the following main conclusions. One, for the Yangtze River Delta region, there is a significant positive effect of digital inclusive finance on per capita carbon emissions, and as the development of digital inclusive finance crosses the threshold, the promotion effect on per capita carbon emissions becomes weaker. Second, the impact of digital inclusive finance on carbon emissions in the Yangtze River Delta region is nonlinear, with a significant single threshold. Initially, digital inclusive finance has a positive contribution to carbon emission per capita, and when it exceeds the threshold, the contribution weakens significantly, indicating that digital inclusive finance has a contribution to carbon emission reduction. Third, there are also threshold effects between all dimensions of digital inclusive finance and carbon emissions, and all of them are significant. Based on the above conclusions, although digital inclusive finance in the Yangtze River Delta region is in the stage of inhibiting carbon emission reduction at this stage, the empirical evidence shows that with the gradual development of digital inclusive finance, its inhibitory effect has significantly slowed down and has turned to a good trend.

Therefore, this paper proposes the following recommendations. First, deepen the digital inclusive finance policy of the Yangtze River Delta and highlight the awareness of "double carbon". While vigorously developing digital inclusive finance, the Yangtze River Delta should unify the layout of green development and emphasize the interaction and cooperation between digital inclusive finance policy and carbon emission reduction. Secondly, we should make reasonable use of regional advantages to build cross-city green technology mutual assistance. The Yangtze River Delta region should give full play to its regional integration advantages and build a platform for sharing science and technology, capital information and human resources based on digital advantages, so as to promote the regional industry as a whole to move towards green, digital and low consumption. Third, expand the scope of "green monitoring" and release targeted green financial products. The Yangtze River Delta region should pay attention to the difficulties and pains of green emission reduction in remote urban areas, small and medium-sized enterprises in real time when coordinating the overall situation, and innovate targeted green financial products to stimulate enterprises' carbon emission reduction spontaneity.

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