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Original Paper

Research on the Impact of Smart City Construction on the Development of Green Economy

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Abstract

The development of green economy is one of the core essences to realize Chinese path to modernization. Based on China's provincial panel data from 2011-2021, this paper uses the entropy weight method to measure the smart city construction index, which includes three dimensions: digitalization, intelligence and informatization; Secondly, a benchmark regression model was used to explore the effect of smart city construction on the development of green economy. Furthermore, a mediation effect model and a threshold regression model were constructed to explore the indirect and nonlinear effects of smart city construction on the development of green economy under the constraint variables of energy utilization efficiency and manufacturing intelligence. Finally, research has shown that the construction of smart cities has shown a positive and direct role in the development of green economy, with a gradient decreasing effect of "western>central>eastern"; The construction of smart cities can indirectly enhance the development of green economy in the region by improving energy utilization efficiency; Based on the characteristics of regional heterogeneity, the construction of smart cities has different threshold effects on the development of regional green economy. When the level of manufacturing intelligence is lower than the threshold value, the construction of smart cities can have a more favorable and positive impact. During the strategic intersection period between smart city construction and the "dual carbon" goal, this article provides scientific basis and theoretical reference for achieving Chinese style green modernization.

Keywords

smart city construction, the development of green economy, benchmark regression, mediation effect, threshold model

1. Introduction

1.1 Research Background

With the promotion of “carbon peak and carbon neutrality” to the height of national strategy, China is entering a period of economic and social green development transformation under the requirements of the “dual carbon” goals. The formulation of *the 14th Five Year Plan* has sparked a new revolution in low-carbon environmental protection and sustainable development in China’s society. The report of *the 20th National Congress of the Communist Party of China* once again pointed out the acceleration of the development of green economy (hereinafter referred to as *DGE*), emphasized the “dual carbon” goals, and expressed the need to actively and steadily promote carbon peak and carbon neutrality. Specific arrangements have been made from the aspects of carbon emission dual control, energy revolution, sound carbon market, and enhanced carbon sink capacity to develop green and low-carbon industries, improve the market-oriented allocation system of resources and environmental factors, accelerate the research and application of advanced technologies for energy conservation and carbon reduction, and promote the application of advanced technologies. Forming green and low-carbon production and lifestyle, clarifying “greening”, “intelligence”, and “digitization” The key direction of collaborative development, has become a powerful lever to achieve the “dual carbon” strategic goals.

More than 800 pilot cities related to smart city construction (hereinafter referred to as *SCC*) have emerged in China, and smart cities are entering a high-speed development channel. At the same time, they are becoming a sustainable, forward-looking, and sustainable solution for building a new urban development pattern. The rapid development of information technology, represented by 5G, Internet of Things, cloud computing, big data, artificial intelligence, blockchain, etc., is fully integrated with the construction of new infrastructure, promoting the high-quality development of *SCC*. An infrastructure system that empowers information infrastructure and integrates infrastructure based on information technology, while providing services such as digital transformation, intelligent upgrading, and integrated innovation for *SCC*. In order to meet the requirements of high-quality development goals and implement the strategic deployment of ecological civilization construction, *SCC*, as a new development model highly integrated with urbanization, digitization, and information technology, is considered an important driving force for empowering green technology innovation.

1.2 Research Content

Unlike previous research, this article proposes a research hypothesis on the impact of *SCC* on *DGE* based on literature and theories related to *SCC* and *DGE*. It aims to deeply explore the complex impact of *SCC* on *DGE*, which may have three contributions: firstly, this article uses the entropy weight method to measure the *SCC* index, and calculates it from three dimensions: digital construction, intelligent construction, and information construction, thereby improving the reliability of research conclusions; Secondly, this article divides China into three major regions, namely the eastern, central, and western, for benchmark regression analysis. It not only explores the direct impact of *SCC* on *DGE*, but also delves into the indirect transmission of *SCC* on regional *DGE* from the perspectives of energy utilization efficiency (hereinafter referred to as *EUE*) and manufacturing intelligence (hereinafter referred to as *MI*). The intermediary effect model is used, and previous studies have mostly examined it from a single dimension. This article uses a segmented linear regression model to study and describe the overall nonlinear forecasting problem, uses a threshold regression model, and conducts a series of stability tests to provide theoretical support for deepening *DGE* of *SCC*; Finally, based on the heterogeneity of development in different regions of China, the article conducts a deep analysis of the nonlinear effects of *SCC* and *DGE*, draws the research conclusions of this article, and proposes targeted suggestions for future *SCC* and *DGE*, thereby contributing theoretical and practical references for China's digital assistance in environmental protection and achieving Chinese style green modernization development.

1.3 Research Significance

1.3.1 Theoretical Significance

The Chinese government has been researching issues related to smart cities since 2010. After years of efforts by experts and scholars, *SCC* has begun to take effect. Currently, people's evaluation of the effectiveness of *SCC* mainly focuses on the economic benefits brought by *SCC*, with less attention paid to the ecological benefits brought by *SCC* (Lin and Wang, 2022). If we focus solely on economic benefits and neglect the construction of ecological civilization, it will be difficult for the economy to sustain high-quality development. Nowadays, while people are pursuing high-speed economic development, they are also paying more and more attention to high-quality economic development. Based on this, this article studies the impact of *SCC* on *DGE* and provides a new perspective, supplementing and improving the theoretical basis between the two, and providing theoretical support.

1.3.2 Realistic Significance

The promotion of *SCC* by the country has brought new opportunities to the economic development of various regions in China, and also created new opportunities for building a more ecologically civilized and environmentally friendly city. Based on this, studying the impact of *SCC* on *DGE* is conducive to practicing the concept of "green mountains and clear waters are like mountains of gold and silver". It can promote regional *DGE*, solve some problems that arise in the urbanization process, and ultimately improve people's quality of life. So, can the SSC drive *DGE*? In what ways does the *SCC* affect *DGE*? This article aims to answer the above questions and provide suggestions for the *SCC* and the promotion of *DGE* in China.

2. Literature Review

2.1 Research on the Construction of Smart Cities

A smart city is the use of various technological means to collect, analyze, process, and transmit urban information to achieve intelligent management and operation of the city. In 2010, the vision of a "smart city" was officially proposed. Since then, China has actively promoted the *SCC*. The construction of smart cities in China has gone through the embryonic stage (before 2010), preliminary exploration stage (2010-2012), rapid development stage (2012-2016), and in-depth research stage (2016 present). With the deepening of research on *SCC*, it has gradually shown a trend of refinement.

Regarding the concept of smart cities, current scholars mainly discuss it from three dimensions, namely information technology, urban functions, and humanistic elements. Overall, research on domestic *SCC* has formed three theoretical perspectives, namely based on information technology, summarizing foreign experiences, and analyzing domestic *SCC* cases (Ge & Hou, 2017). The definition of the concept of "smart city" can be divided into three categories, namely the "intelligent" type defined from a technical perspective, the "intelligent" type defined from a target perspective, and the "intelligent" type defined from a system perspective (Wu & Chen, 2022). From a technical perspective, smart cities are an information-based, modernized, and new urban operation model. From the perspective of urban development, *SCC* is moving towards a new stage, and it will promote coordinated development of economy, society, and nature (Yang, 2023).

2.2 Research on DGE

British environmental economists Pierce et al. first proposed the term "green economy" in their Green Economy Blueprint in 1989, and pointed out that "green economy is based on social and ecological conditions in order to establish a sustainable economy". In 2012, environmental protection was included in the overall layout of the "Five in One" initiative. The 14th Five Year Plan emphasizes the strategic position of green development, indicating that *DGE* has become one of the core strategies for national development today (Li et al., 2023). In the context of green and low-carbon economic development, the main ways for sustainable development in the new era are innovation, recycling, low-carbon, and green. The improvement of green productivity is a high-level requirement for economic development in today's era (Shang & Wang, 2023). *DGE* requires regions to achieve economic growth through a green model of high efficiency, low pollution, and low loss.

With the *SCC*, the continuous integration of digital technology and economic development has provided new impetus for the growth of green economy. Scholars have conducted research on the impact of information exchange, technological innovation level, and regional cooperation on *DGE*, and have concluded that *DGE* is influenced by multiple factors (Wei & Hou, 2022). Scholars analyze *DGE* from three perspectives: social development, economic benefits, and innovation drive. The implementation path and influencing factors of *DGE* are increasingly receiving attention from scholars (Xu et al., 2021). Existing research mainly focuses on environmental factors, technological innovation, and economic transformation to study green development. The technological innovation, industrial upgrading, and resource allocation optimization of smart cities are conducive to the transformation of green economy and the improvement of green total factor productivity (Fan & Mi, 2021).

3. Mechanism Analysis and Research Hypotheses

3.1 Direct Transmission Mechanism and Research Hypotheses

Smart cities have developed in response to the practical needs of promoting technological revolution and achieving urban modernization, with the aim of achieving comprehensive development of urban economy, society, ecology, and other aspects by enhancing overall harmonious intelligence (Hu et al., 2021). On the one hand, *SCC* use smart concepts to plan cities, rely on smart means to govern cities, and use high and new technologies such as the Internet and cloud computing to conduct digital grid management on the complex systems of smart cities, so that the various subsystems of cities can penetrate and integrate with each other, which is conducive to reducing energy and material consumption, improving resource utilization, protecting ecosystems, and promoting the coordination of economic development and ecological civilization construction. On the other hand, *SCC* places greater emphasis on development resilience, forcing enterprises to undergo green transformation in technology, equipment, concepts, and other aspects by creating new development paths. When ecological products can create certain economic benefits, the increase in economic benefits can further promote the sustainable use of ecological resources, thus forming a virtuous cycle and achieving sustainable development.

Research hypothesis 1: *SCC* can directly promote *DGE*.

3.2 Indirect Transmission Mechanisms and Research Hypotheses

The coverage depth and breadth of smart cities in China are constantly increasing, and the development of smart transportation, smart healthcare, and other industries is affecting the construction of urban green economy. However, China's *DGE* still faces the problems of extensive economic development and high energy consuming industries with carbon emissions. Therefore, improving the *EUE* is a powerful guarantee for promoting *DGE* in smart cities. Therefore, based on the above analysis, this article focuses on analyzing the mediating role of *EUE* factors in *DGE* in *SCC*.

The improvement of *EUE* can reduce energy consumption, lower pollutant emissions, and play a positive role in *DGE* in *SCC*. Firstly, the improvement of *EUE* requires innovation in energy technology, thereby promoting the agglomeration of innovative factors, transforming the energy utilization methods of upstream and downstream enterprises in the industrial chain, and improving the degree of effective energy utilization. Furthermore, it will further promote the transformation and upgrading of industries, change the traditional extensive utilization of energy, improve energy efficiency, and promote the regional *DGE* (Yang et al., 2023). To promote the regional *DGE*, technological innovation should be carried out, and a series of coordinated and cooperative measures should be combined to improve *EUE*, which is conducive to promoting the growth of regional green economic efficiency and high-quality development.

Research hypothesis 2: *EUE* plays a mediating role in *DGE* of *SCC*.

3.3 Nonlinear Conduction Mechanisms and Research Hypotheses

Based on network externalities and the Metcalfe rule, the *SCC* is likely to have a non-linear impact on *DGE*. Given the uneven regional development in China, the impact of *SCC* on *DGE* may vary across provinces and regions.

The *MI* can reduce waste and achieve economic circulation, promote sustainability considerations in product design and manufacturing processes, improve product reuse and recycling efficiency. This non-linear effect will bring greater resource protection and environmental benefits.

Research hypothesis 3: *DGE* of *SCC* plays a positive non-linear role under the influence of *MI*.

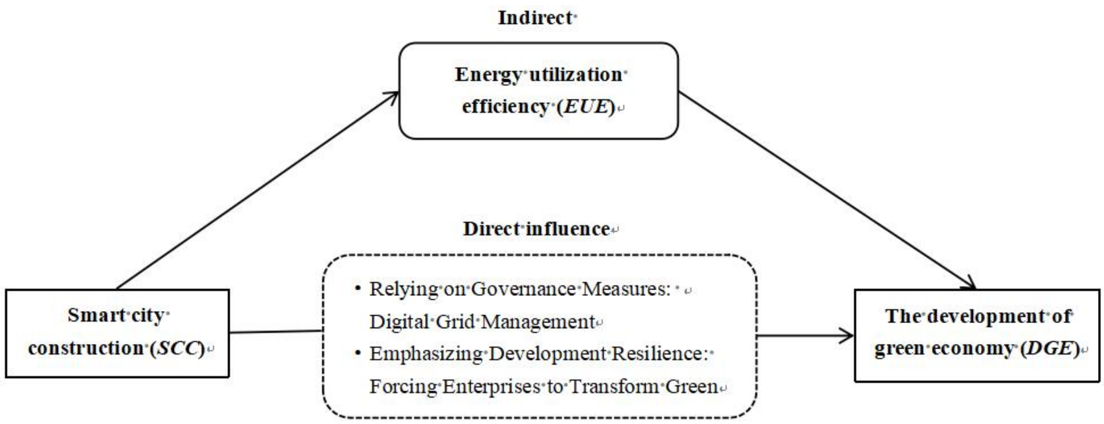

Figure 1. Theoretical Framework Diagram of the Impact of *SCC* on *DGE*

4. Data Sources and Analysis

4.1 Variable Measurement and Explanation

4.1.1 The Dependent Variable

DGE. Coordinating economic development with ecological civilization construction has become a key focus, promoting sustainable economic development, and *DGE* has become the trend. Since the reform and opening up, China's extensive economic development model has seriously damaged the ecological environment, and China has become the world's largest emitter of sulfur dioxide. Sulfur dioxide, as a major component of emissions, seriously affects air quality and has already affected the survival of humans, animals, and plants. It is used as a substitute for environmental pollution. Scholars use sulfur dioxide to represent exhaust emissions (Guo & Zhang, 2023), while others use sulfur dioxide emissions as an unexpected output for regional *DGE* (Ma, 2023). In the article Indicator Tools and Empirical Research for Green Economy Decision Making jointly released by the Ministry of Environmental Protection and the World Wildlife Fund in 2015, the concept and connotation of green economy were scientifically defined, and reasonable measurement indicators were proposed. SO2 emissions are one of the core indicators, so this article selects sulfur dioxide emissions as the proxy variable for *DGE*.

4.1.2 Core Explanatory Variables

SCC. The *SCC* is mainly measured from three single aspects: digitization, intelligence, and informatization (Ma & Chen, 2023; Wang, 2023). Based on existing provincial-level data, this article further expands the measurement scope of *SCC* and evaluates the comprehensive development level of *SCC* in various regions from three aspects: digitalization, intelligence, and informatization. Among them, digitalization is measured from two aspects: regional innovation capability and digital economy development. Regional innovation capability is represented by Tian et al. (2022), represented by the number of patent applications in the electronic and communication equipment manufacturing industry, and digital economy development is represented by Liu et al. (2023), represented by R&D expenditure in the digital economy industry; Intelligence includes the economic benefits of intelligence and the research and development of intelligent devices. The economic benefits of intelligence are measured by the revenue of the electronic and communication equipment manufacturing industry, while the research and development of intelligent devices is measured by the investment in the development of new products in the electronic computer and office equipment manufacturing industry; Informatization includes communication equipment R&D and Internet penetration. Communication equipment R&D is measured by expenditure on new product development of electronic and communication equipment manufacturing industry, and Internet penetration is measured by the number of Internet broadband access households.

Table 1 lists the various sub indicators of *SCC*. The evaluation index system for the degree of *SCC* has multi-level and multi indicator characteristics, and the key to evaluating such multi-attribute problems lies in the determination of the weights of each indicator. We use the objective weighting method to capture the objective attributes of each indicator and try to avoid the arbitrariness of subjective weighting. Entropy weighting method is a commonly used objective weighting method. Entropy is generally used to measure the uncertainty and randomness of things, and also to judge the degree of dispersion of things. The greater the degree of dispersion, the greater the impact on the comprehensive evaluation. Therefore, we use the entropy weight method to determine the weight of indicators, and then objectively evaluate and analyze the evaluation objects.

Table 1. *SCC* index Calculation System

Primary indicators	Secondary indicators	Specific indicators
Digital construction	Regional innovation capability	Number of patent applications for electronic and communication equipment manufacturing industry
	Development of digital economy	R&D expenditure on digital economy industry
Intelligent construction	Intelligent economic benefits	Revenue from electronic and communication equipment manufacturing industry
	Research and development of intelligent devices	Investment in research and development of new products in the electronic computer and office equipment manufacturing industry
Information construction	Research and development of communication equipment	Expenditures for new product development in the electronic and communication equipment manufacturing industry
		Number of Internet broadband access households

	Internet popularity	

4.1.3 Mediating Variable

Based on the previous theoretical analysis, this article selects *EUE* as the mediating variable for empirical research. Improving *EUE* can reduce energy resource waste, suppress disorderly and excessive use of resources, and reduce pollution during energy use. This article refers to the research of scholars such as Sun (2022) and uses the ratio of GDP to total energy consumption to characterize *EUE*.

4.1.4 Threshold Variable

This article selects *MI* as the threshold variable for empirical research. Drawing inspiration from Sun et al. (2019) and Wang et al. (2022), *MI* indicator system was constructed from three levels: basic input layer, production application layer, and market benefit layer for measurement. At the same time, the entropy weight method adopted by Li (2022) for the calculation of *MI* was used to weight and calculate various indicators, which is consistent with the calculation method of *SCC* index mentioned earlier.

Table 2. Measurement System for *MI* Index

Primary indicators	Secondary indicators	Specific indicators
Basic investment	Talent investment	Total R&D personnel in high-tech industries
	Machine input	Robot installation density
Production applications	The degree of technological marketization	Technology market transaction volume
	Software business revenue	Software business revenue
Market benefits	Economic benefits	High tech market profit
	Social benefits	Electricity consumption per unit GDP

4.1.5 Control Variables

The effect of *DGE* is not only influenced by the *SCC*, but also by many internal and external factors. Drawing on existing research, in order to ensure the robustness of the model results, this article adds a series of control variables, including human capital (hereinafter referred to as *HC*), industrial structure (hereinafter referred to as *IS*), and technological maturity (hereinafter referred to as *TM*). ① *HC*. Drawing on scholars such as Xiao (2023), the average number of students in higher education institutions per 100000 population is used as a measure. The larger the stock and higher the quality of *HC*, the faster it can transform knowledge into productivity, apply theoretical achievements to reality, and better *SCC*. ② *IS*. The layout and *IS* will affect the quality and efficiency of *SCC*. This article draws on the research of Liu et al. (2021) and uses the ratio of the added value of the tertiary industry to the added value of the secondary industry to measure it. ③ *TM*. *TM* is closely related to the development of green economy in various regions, and is an important focus of research on the development of green economy. Therefore, it is characterized by the transaction volume of the technology market.

4.2 Data Source and Processing

This paper selects 30 regions in China from 2011 to 2019 as research samples. Due to the obvious lack of energy data in Hong Kong, Macao, Taiwan and Xizang, we have eliminated them. The data is sourced from the China Statistical Yearbook, China Environmental Statistical Yearbook, China Electronic Information Industry Statistical Yearbook, and China High tech Statistical Industry Yearbook. In order to improve the accuracy, credibility, and avoid heteroscedasticity and multicollinearity of estimates, logarithmic processing is applied to the relevant variables, and linear interpolation method is used to fill in the missing data in some years of the region.

Table 3 reports the correlation coefficient matrix between variables used in this article. From the table, it can be seen that the correlation coefficient between *SCC* and *DGE* is -0.015, indicating a certain positive correlation between *SCC* and the level of *DGE*. This result also preliminarily verifies the conclusion of this article. In addition, the correlation coefficient matrix results show that there is no significant correlation between variables, which to some extent alleviates concerns about collinearity in the regression model and can be used for subsequent regression analysis.

Table 3. Correlation Matrix and Descriptive Statistics of Various Variables

Variable	*DGE*	*SCC*	*HC*	*IS*	*TM*
DGE	1.000				
SCC	-0.015^{***}	1.000			
HC	-0.408^{***}	0.168^{***}	1.000		
IS	-0.721^{***}	0.003	0.490^{***}	1.000	
TM	-0.209^{***}	0.459^{***}	0.687^{***}	0.318^{***}	1.000
Obs	300	300	300	300	300
Mean	3.379	0.075	7.837	1.324	13.940
SD	1.164	0.129	0.285	0.729	1.790
Min	-1.715	0.000	6.987	0.527	8.642
Median	3.648	0.030	7.799	1.171	13.973
Max	5.208	1.000	8.633	5.244	17.961

Note. *** represents significance at the 0.01 level, ** represents significance at the 0.05 level, and * represents significance at the 0.1 level. (The following table is the same as)

5. Research Design

5.1 Model Construction

5.1.1 Benchmark Regression Model

This article uses benchmark regression model, mediation effect model, and threshold regression model to examine the direct, indirect, and nonlinear effects of *SCC* on regional *DGE*, respectively, in order to test the three hypotheses proposed in this article. This article introduces the *SCC* index to analyze the level of *DGE* in 30 provinces, and constructs a benchmark regression model as follows:

$$DGE_{it} = \alpha_0 + \alpha_1 SCC_{it} + \alpha_n C_{it} + \lambda_i + \varepsilon_{it} \tag{1}$$

Among them, DGE_{it} represents the level of green economic development in the region i in t year, which is the core variable of this article. SCC_{it} represents the comprehensive index of smart city construction in the region i in t year, and C_{it} represents the control variables in the model, including HC_{it} , IS_{it} and TM_{it}. In addition, in equation (1), α_0 represents the intercept term, λ_i represents unobservable individual random effects, and ε_{it} is a random interference term.

5.1.2 Mediation Effect Model

Furthermore, this article introduces *EUE* as a mediator variable and uses a mediation effect model to study the indirect impact mechanism of *SCC* on *DGE*. The constructed model is as follows:

$$EUE_{it} = \alpha_0 + \alpha_1 SCC_{it} + \alpha_n C_{it} + \lambda_i + \varepsilon_{it} \tag{2}$$

$$DGE_{it} = \omega_0 + w_1 SCC_{it} + w_2 EUE_{it} + w_n C_{it} + \lambda_i + \varepsilon_{it} \tag{3}$$

EUE_{it} represents the mediator variables in the model, α_0 represents the intercept term, SCC_{it} represents the comprehensive index of *SCC* in the region i in t year, DGE_{it} represents the level of green economic development in the region i in t year, C_{it} represents the control variables in the model, ω is the corresponding coefficient vector.

5.1.3 Threshold Regression Model

Hansen's non dynamic panel threshold regression model, as a non-linear relationship testing econometric model, can accurately calculate threshold values and test the threshold effect between *SCC* and *DGE*. As a non-linear relationship testing econometric model, this method can accurately calculate threshold values and perform significance testing on endogenous "threshold features". This article takes *MI* as the threshold variable and establishes a single threshold model as follows:

$$DGE_{it} = \mu_i + \theta_1 SCC_{it} \cdot I(threshold_{it} \leq \gamma) +$$

$$\theta_2 SCC_{it} \cdot I(threshold_{it} > \gamma) + \theta_n C_{it} + \varepsilon_{it} \quad (4)$$

DGE_{it} represents the level of green economic development in the region i in t year, SCC_{it} represents the comprehensive index of smart city construction in the region i in t year, θ is the corresponding coefficient vector, γ is the threshold value, $I(\bullet)$ is the indicator function, and takes a value of 1 when the corresponding conditions are met. Otherwise, it is 0, $\varepsilon_{it} \sim idd(0, \delta^2)$ indicating random interference.

5.2 Empirical Research Results

5.2.1 Benchmark Regression Analysis

Using the Hausman test to select an estimation model, this article concludes that selecting a fixed effects model is more reasonable. The benchmark regression results are shown in Table 4, where Model (1) represents the estimated sample results for the whole country, Model (2) represents the estimated model results for the eastern region, Model (3) represents the estimated model results for the central region, and Model (4) represents the estimated model results for the western region. In Model (1), the coefficient of influence of *SCC* on *DGE* is -1.598, which is significant at the 1% level, indicating that *SCC* has a positive impact on the overall *DGE*, verifying the hypothesis 1 of this study: *SCC* can directly promote *DGE*. Smart city is the product of modern information technology revolution and rapid knowledge economy. *SCC* can realize digital grid management of complex systems in cities through a series of emerging technologies such as the Internet and cloud computing, and promote *DGE*. In terms of controlling variables, *HC* promotes the national *DGE* at a significance level of 1%. *HC* can transform knowledge into productivity, apply theory to practice, and at the same time, people with higher quality have stronger environmental protection awareness, reducing resistance to the development of the green economy; The *IS* promotes the national *DGE* at a significance level of 1%, and the *IS* is increasingly optimized. The proportion of the secondary industry, including mining, manufacturing, and gas, has decreased, while the proportion of the tertiary industry, including high-tech industries, has increased, which has a promoting effect on *DGE*; The coefficient of influence of *TM* on *DGE* is -0.140, which is significant at the 1% level. The continuous maturity and development of technologies such as artificial intelligence and big data have achieved deep integration in the fields of carbon footprint and carbon sink. It can predict and plan various energy enterprises and industries in the region, reduce energy consumption, and promote *DGE*.

According to models (2) - (4), it can be concluded that the impact of *SCC* on *DGE* shows a trend of "western>central>eastern". This article believes that the main reason is that compared to the western and central regions, on the one hand, the initial technological endowment in the eastern region is relatively high, but the issue of innovation efficiency is prominent. The eastern region has made significant improvements in pollutant emissions and governance by using advanced technology and equipment, and there is limited space for information technology, big data, and other factors to release the dividends of *DGE*; On the other hand, both technological efficiency and scale efficiency show a significant convergence trend. The management system and innovation scale in the western and central regions are both latecomer, and the *SCC* can also fully play a role in promoting *DGE* and bring greater benefits.

Table 4. Benchmark Regression Results

	(1)	(2)	(3)	(4)
	Nationwide	Eastern region	Central region	Western region
SCC	-1.598***	-1.018	-4.728*	-9.609***
	(-3.03)	(-1.43)	(-1.72)	(-3.25)
HC	-1.260***	-0.464	-1.993***	-1.428***
	(-4.10)	(-0.53)	(-3.08)	(-3.82)
IS	-1.714***	-1.878***	-0.717***	-1.433***
	(-14.18)	(-9.45)	(-3.51)	(-5.19)
TM	-0.140***	-0.278***	-0.224***	0.007
	(-2.95)	(-2.63)	(-2.89)	(0.12)
_cons	17.600***	14.014**	23.408***	16.386***
	(8.40)	(2.23)	(4.96)	(6.66)
N	300	110	80	110
R^2	0.752	0.794	0.807	0.749
Adj. R^2	0.72	0.76	0.78	0.71

5.2.2 Mechanism Effect Analysis

Table 5 reports the test results of the mediating mechanism of the impact of *SCC* on *DGE*. Based on the coefficient and significance level of the core variables and mediating variables in the model, it can be concluded that under the influence of *EUE*, *SCC* has an indirect impact on *DGE* to a certain extent, providing sufficient evidence for the hypothesis of this study.

Specifically, the Sobel test results of Model (5) and Model (6) using *EUE* as the mediator variable show that the impact of *SCC* on *EUE* is significantly positive, with a negative correlation coefficient of

2.179. *EUE* can significantly promote *DGE*, with an impact coefficient of -0.586. Therefore, the regression coefficient product of the two is significantly negative, and P=2.242e-07<0.1 is significant, indicating that *SCC* has a positive impact on *DGE* by promoting *EUE*. This result is consistent with the research findings of Zhao and Jia (2013), confirming that *SCC* can effectively improve *EUE* and indirectly promote *DGE*. Therefore, research hypothesis 2 is valid.

Overall, the *SCC* has a positive indirect impact on *DGE* under the path of *EUE*. This indicates that *SCC* not only affects *DGE* through direct spillovers, but also indirectly affects *DGE* through the induction mechanism of *EUE* to a certain extent.

Table 5. Mechanism Verification of the Impact of *SCC* on *DGE*

	(5)	(6)
	EUE	*DGE*
SCC	2.179^{***} (0.252)	0.805^{***} (0.437)
HC	0.867^{***} (0.150)	-0.155 (0.244)
IS	0.362^{***} (0.044)	-0.887^{***} (0.076)
TM	0.070^{***} (0.025)	0.136^{***} (0.039)
EUE		-0.586^{***} (0.090)
_cons	-6.734^{***} (0.965)	4.800^{***} (1.612)
Sobel test	Z=-5.178 P=2.242e-07	
Bootstrap test1	Z=-3.800 P=0.000	
N	300	300
R^2	0.638	0.592

5.2.3 Analysis of Nonlinear Effects

Before conducting threshold regression, it is necessary to test the existence of threshold effects in the model. This article underwent Bootstrap repeated sampling, and the results showed that all three did not pass the double threshold test. The *MI* has passed the single threshold effect at a significance level of 1%, and research hypothesis 3 is valid. The non-linear impact of *SCC* on *DGE* has been verified under the threshold variable of *MI*. In order to observe the estimation and confidence interval of the threshold value more clearly, the least squares likelihood ratio statistic LR is used to identify the threshold value. The threshold estimated value is the value when LR is zero. Next, the likelihood ratio function diagram of a single threshold value for *MI* is drawn, as shown in Figure 2.

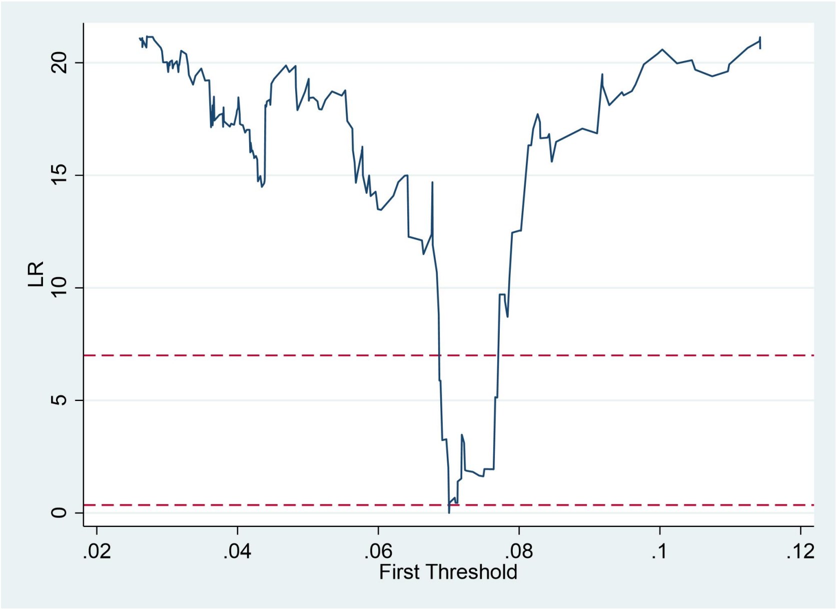

Figure 2. Likelihood Ratio Function Diagram of Various Threshold Variables: *MI*

Table 6 reports the threshold panel regression results of the impact of *SCC* on *DGE*. Specifically, the constraint effects of each threshold variable are as follows: Model (11) represents the estimated results of the model when *MI* is used as the threshold variable. As the level of regional *MI* crosses the threshold value of 0.070, the effect of *SCC* on *DGE* changes from negative correlation to positive correlation, from 4.601 to -1.391. It can be concluded that in areas with higher levels of *MI*, *SCC* has a better effect on improving *DGE*, providing strong support for the hypothesis of this study.

Table 6. Threshold Regression Results

	(11)
	DGE
Threshold variable	*MI*
Threshold value	0.070
SCC·I (threshold≤γ)	4.601*** (1.559)

SCC·I (threshold>γ)	-1.391*** (0.514)
HC	-1.535*** (0.305)
IS	-1.704*** (0.117)
TM	-0.109*** (0.047)
_cons	19.209*** (2.068)
F	38.97
N	300
R^2	0.4360

5.2.4 Robustness Test

To examine the robustness of the results, this study conducted a robustness test on the impact of *SCC* on *DGE* through three methods: changing the dependent variable, reducing the control variable, and adjusting the research sample (see Table 7 for the results). ① Considering the lag in *DGE*, this article adopts *DGE* with a lag of one year as the new dependent variable. At the same time, in order to solve the problem of right truncation of samples, this paper excluded the 2020 related variable data, and the model coefficients and significance levels were still basically consistent with the research results of this paper, verifying the robustness of the model results in this paper; ② This article draws on the robustness test method of Sun and Deng (2022) and conducts a robustness test to reduce control variables. After excluding technological maturity, regression analysis is conducted on the impact of *SCC* on *DGE*. The analysis shows that *SCC* still has a significant positive impact on *DGE*, which is consistent with the basic regression results. ③ This article adjusts the research sample to test the possible bias of outliers on the results and verify the robustness of the previous study. Delete the sample areas with the highest and lowest *SCC* index of around 1%, 5%, and 10% in sequence, and conduct three model tests on 28 regions, 26 regions, and 24 regions in China. The explanatory variable influence coefficient and significance level in the results are similar to the previous test results, without significant differences, and also show strong robustness. (Due to space limitations, this article only lists empirical results from 26 regions)

Table 7. Robustness Test

	(13) L.*DGE*	(14) Reduce variable	(15) 26 samples
SCC	-1.805^{***} (-3.61)	-1.837^{***} (-3.47)	-7.977^{***} (-5.49)
HC	-0.264 (-0.90)	-1.739^{***} (-6.57)	-0.746^{**} (-2.27)
IS	-1.532^{***} (-14.61)	-1.887^{***} (-17.61)	-1.581^{***} (-12.84)
TM	-0.162^{***} (-3.90)		-0.109^{***} (-2.07)
_cons	9.943^{***} (4.89)	19.645^{***} (9.80)	13.311^{***} (5.88)
N	270	300	260
R^2	0.742	0.744	0.773

6. Research Conclusions and Recommendations

6.1 Research Summary

Based on the goal of "Chinese path to modernization" by driving *DGE* with *SCC*, this paper explains the impact of *SCC* on regional *DGE* from three aspects: basic effect, indirect transmission mechanism and nonlinear effect, based on China's provincial panel data from 2011 to 2020. When measuring the *SCC* index, it includes three dimensions: digital construction, intelligent construction, and information technology construction. In addition, this article uses panel fixed effects model, mediation effects model, and threshold regression model to explore the complex relationship between *SCC* and *DGE* from three levels: national level, three major regions, and provincial level. The main conclusions are as follows:

1) The *SCC* can play a significant positive role in improving *DGE* and exhibit the characteristics of "western>central>eastern"; 2) The *SCC* also has varying degrees of indirect impact on *DGE*, manifested in indirectly improving the level of *DGE* by improving *EUE*; 3) The *SCC* has a significant threshold effect on *DGE*. In areas with higher levels of *MI*, the *SCC* has a better promotion effect on *DGE*.

6.2 Suggestions and Outlook

1) Continuously promote *SCC*, and move towards the goal of more efficient urban management and a more livable ecological environment. Promoting the *SCC* is a major project that cannot be completed overnight. It requires the joint efforts of various stakeholders such as the government, enterprises, and the people. The government should actively promote the various conveniences brought by smart cities,

implement policies that are conducive to the *SCC*, encourage enterprises to undergo green transformation, promote the trend of building smart cities in the whole society, and promote the *SCC*. Enterprises should actively respond to government policies, clarify the responsibilities of green production and operation entities, strive to seize the new opportunities brought by the country's promotion of *SCC*, actively introduce green equipment and technology, and accelerate green transformation. The people should actively understand the various policies on *SCC* issued by the policy, and strive to provide suggestions and strategies for *SCC*, concentrating the wisdom of the masses.

2) Pay attention to the issue of regional development imbalance in the *SCC* and promote regional coordinated development. The initial technological endowment in the eastern region is relatively high, and such areas should guard against arrogance and impatience and steadily promote the *SCC*. Compared to the eastern region, the *SCC* has a more significant impact on *DGE* in the western and central regions. The western and central regions should fully utilize the opportunity of national *SCC*, increase investment in digital economy infrastructure such as cloud computing engineering and 5G technology, improve the talent training system, actively introduce talents, seize the dividends of *DGE*, and better play the role of *SCC* in promoting *DGE*.

3) We should explore the development path of *SCC* with regional characteristics based on the actual situation in different regions of China. In the process of *SCC*, attention should be paid to the coordinated development of digitization, intelligence, and informatization. Drawing on successful cases of *SCC*, combined with the characteristics and practical problems of one's own city, design plans that are in line with the actual development situation of one's own city, strengthen coordination and industrial linkage between cities and regions, so that information technology can better empower industrial transformation and upgrading and enterprise innovation, thereby achieving development of *MI*, reducing carbon emission intensity, improving the effect of *SCC* on *DGE*, promoting the intelligent processing of modern cities, and promoting the high-quality of *DGE* in smart cities.

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