

# On Measurement and Improvement Measures of Digital Empowerment Carbon Emission Reduction Effect

## -- Taking the Yangtze River Delta Urban Agglomeration as an Example

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### Abstract

In order to explore the specific impact and mechanism of digital economy development on regional carbon emissions, based on the Panel data of 26 major cities in the Yangtze River Delta region from 2011 to 2019, this paper establishes a regression model to verify the fixed effect model and intermediary model of digital economy development enabling carbon emission reduction. The results show that digital economy development can significantly reduce regional carbon emission intensity. Among them, factors such as digital industry development and digital technology innovation play a major role. The digital economy can effectively reduce carbon emissions by optimizing industrial structure. The strong driving force of the digital economy has become a catalyst for carbon reduction. Therefore, China should place the digital economy in an important strategic position, and the trend of developing and strengthening the digital economy is urgent.

### Keywords

Digital Economy; Carbon Reduction; Mesomeric Effect; Yangtze River Delta Urban Agglomeration.

## 1. Introduction

The "dual carbon" goal is one of the most distinctive development strategies of the times in China's 14th Five Year Plan. In order to cope with the severe form of global warming, China has proposed low-carbon environmental protection policies from multiple aspects. The digital economy stands out among numerous carbon reduction measures due to its low energy consumption and low emissions.

The China Digital Economy Development Report (2022) shows that in 2021, the scale of China's digital economy reached 45.5 trillion yuan, accounting for 39.8% of GDP. The digital economy plays a crucial role in the national economy and plays a crucial role. Can the digital economy promote the reduction of regional carbon emissions, and if so, how does it affect carbon emissions? Exploring the above issues will help us comprehensively understand the mechanism of the digital economy.

## 2. Literature Review

The digital economy entered the academic community relatively late, and related research also started relatively late. However, in the digital wave, the driving force brought by the digital economy to social development and economic change is becoming increasingly strong, thus

gradually becoming a hot topic of research for scholars. Reviewing and reviewing existing literature, this article provides a comprehensive review from three aspects: the connotation, measurement, and impact of the digital economy.

The term "digital economy" appeared in the 1990s and was first proposed by Tapscott, the father of digital economics, in 1996. However, Tapscott did not provide a specific connotation of the digital economy. With the continuous development of the digital economy, governments and scholars from multiple countries have conducted in-depth discussions on its connotation.

The definition of the digital economy has not been unified, and there are also differences in the measurement methods of the digital economy in the academic community. In their research, scholars have adopted different methods to measure the development of the digital economy. For example, L.P. Rai (2000) proposed a calculation method for the social informatization index; Li Guoqiu (2016) used a simple arithmetic mean method to measure the European digital economy and social index; Zhang Xueling and Jiao Yuexia (2017) took information and communication technology as the core, considered infrastructure, technology application, enterprise and industrial development and other aspects, and used weights to calculate comprehensive indexes and sub indexes when building the indicator system to reflect the development of China's digital economy; Liu Jun et al. (2020) constructed evaluation indicators for the digital economy from three perspectives: information technology development, internet development, and digital trade development, and evaluated the development of the digital economy in various provinces across the country.

In the relevant literature on carbon emissions, scholars have explored and analyzed such issues from different perspectives and methods. Most scholars have focused on studying the factors that affect carbon emissions. These factors include economic growth, urbanization level, financial development, industrial structure, technological development, foreign direct investment, environmental regulations, and energy structure. For example, Khalid Zaman (2017) found that there is an international transfer phenomenon in carbon emissions, resulting in an inverted U-shaped relationship between their own carbon emissions and economic growth described by EKC; The study by Hossny Azizalrahman and ValidHasyimi (2019) shows that the impact of urbanization on carbon emissions is opposite to energy consumption and trade openness in high-income and low to middle-income groups; Xu Runong and Wu Yuming (2016) pointed out through their research on the Yangtze River Delta urban agglomeration that with the increase of urbanization rate, energy intensity will show a downward trend; Scholars such as Zhang Yuejun et al. (2016), Li Shouguo, and Song Baodong (2019) have concluded through empirical research on different regions of China that the impact of financial development on carbon emissions has phased characteristics; Sun Pan et al. (2018) used the spatial Durbin econometric model to test and found that the rationalization and upgrading of industrial structure will promote carbon emissions reduction; Xie Junjie (2017) found that technological progress can improve the efficiency of traditional fossil energy utilization, promote industrial structure upgrading, and reduce carbon dioxide emissions per unit of GDP.

### **3. Theoretical Analysis and Research Hypotheses**

#### **3.1. Direct Impact of Digital Economy on Carbon Emissions**

The digital economy can directly affect carbon emissions, mainly reflected in the following aspects: the development of digital technology can help improve resource utilization efficiency, reduce resource waste and carbon emissions. Optimize energy allocation, reduce energy waste and carbon emissions. Digital technology has driven the development of remote work and e-commerce, reducing people's commuting and logistics transportation, thereby reducing carbon emissions. Through remote work, people can choose their workplace more flexibly, reducing traffic congestion and energy consumption. E-commerce not only reduces the presence of

physical stores, but also reduces inventory and logistics links, reducing energy and carbon emissions. Digital technology provides the ability to collect, process and analyze environmental data. Through the analysis of Big data, we can better understand the sources and influencing factors of carbon emissions and provide scientific basis for environmental protection. At the same time, digital technology can also help achieve information sharing and collaboration, promoting the dissemination and application of knowledge related to carbon emissions reduction.

Overall, the development of the digital economy not only brings about economic growth and social progress, but also directly affects carbon emissions, providing new technologies and innovative means for carbon reduction.

### 3.2. The Mediating Role of the Digital Economy in Carbon Emissions

The development of the digital economy also indirectly affects carbon emissions, mainly including the following aspects:

The digital economy promotes the upgrading and optimization of traditional industries and reduces energy consumption and carbon emissions by promoting industrial informatization and Digital transformation. For example, through the Internet of Things and Big data technology, we can achieve intelligent manufacturing and intelligent energy management, improve production efficiency and energy utilization efficiency, and thus reduce carbon emissions. Developing low-carbon industries: The digital economy has driven the development of many emerging low-carbon industries. For example, the renewable energy industry, clean energy technology research and development, energy-saving and environmental protection products, etc. Through the application and innovation of digital technology, these industries can reduce carbon emissions during production and use, playing an important role in reducing global greenhouse gas emissions.

In summary, the digital economy promotes the development of low-carbon industries, guides low-carbon consumption, and provides carbon reduction solutions by optimizing industrial structure, while promoting carbon reduction in traditional industries.

## 4. Research Design

### 4.1. Model Construction

To investigate the direct impact of the digital economy on the intensity and efficiency of urban carbon emissions, the following fixed effects model is constructed.

$$\ln CE_{it} = \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 \sum X_{it} + \mu_i + v_i + \varepsilon_{it} \quad (1)$$

Among them,  $i$  represents the province,  $t$  represents the year, the dependent variable  $CE_{it}$  represents the carbon emission intensity of each province, and  $Digit$  is the core explanatory variable of this article, representing the level of digital economy development in each region. The regression coefficient  $\alpha_1$  reflects the degree of impact of the digital economy on regional carbon emissions.  $X_{it}$  is a series of control variables,  $\mu_i$  is the fixed effect of the region,  $v_i$  is a fixed time effect,  $\varepsilon_{it}$  is a random perturbation term.

Select carbon emission intensity  $CE_{it}$  as the dependent variable, the level of digital economy development as the core explanatory variable, and total population, environmental factors, etc. as control variables for empirical analysis to explore the mechanism of the impact of digital economy development on carbon emissions.

To explore the indirect mechanism of carbon reduction effects in the digital economy, the following intermediary model is constructed.

$$M_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_2 \sum X_{it} + \mu_i + v_i + \varepsilon_{it} \tag{2}$$

$$\ln CE_{it} = c_0 + c_1 Dig_{it} + c_2 M_{it} + c_3 \sum X_{it} + \mu_i + v_i + \varepsilon_{it} \tag{3}$$

### 4.2. Variable Selection

(1) Explained variable: carbon emission intensity. According to the existing methods, this paper calculates the total annual carbon dioxide emissions of each Prefecture-level city to get the carbon emission intensity.

(2) Core explanatory variable: Digital Economy Index. With digital technology development as the core, the digital economy development index of each region is measured in combination with the Digital Financial inclusion Index (2011-2020). The development indicators of digital technology are divided into three dimensions: digital industry infrastructure, revenue situation, and employee base. Digital industry infrastructure is measured by the number of mobile phone users and international internet broadband users, revenue situation is measured by telecommunications and postal business income, and employee base is measured by the number of employees in transportation, warehousing, and postal industries, as well as the number of employees in information transmission, computer services, and software industries. Finally, the digital economy development index was calculated using the principal component method.

**Table 1.** Variable Selection

Variable	Variable Symbol	Meaning of variables	Method of calculation
Explained variable	Ln CE	Carbon emissions	Statistical total carbon emissions
Core explanatory variable	Dig	Digital Economy Level	Entropy weight method
Control variables	Ln in	Income level	Per capita income of urban residents
	Ln ele	Energy consumption	Per capita electricity consumption
	Ln pop	Population size	Total population at the end of the year
	Gov	Government budget	General budget expenditure/GDP of local finance
	Pol	Environmental pollution	Environmental pollution index

(3) Control variables. In order to control multiple factors that affect carbon dioxide emissions, this article introduces some relevant variables to improve the accuracy of the results of the impact of the digital economy on carbon emissions. These control variables include residents' wealth level, population size, environmental pollution, energy consumption, and government support. In terms of residents' wealth level, we use the per capita income of urban residents as a measurement indicator. The per capita income level of a region reflects its economic development level and residents' income level, while also having a significant impact on energy consumption level and carbon dioxide emissions. The population size is measured by the total urban population. Previous studies have shown that the contribution of households to carbon dioxide emissions cannot be ignored, so population size plays an important role in influencing carbon emissions. In terms of environmental pollution, industrial wastewater emissions, industrial sulfur dioxide emissions, and industrial solid waste emissions are usually used in research to measure the environmental pollution status of a region. In terms of energy consumption, as China is a major coal consumer, coal is one of the main sources of carbon

emissions. Therefore, this paper selects the per capita electricity consumption of Prefecture-level city as an indicator to measure energy consumption. In terms of government support, the intervention behavior of local governments has a significant impact on economic development, industrial structure adjustment, and technological innovation level. This paper uses the proportion of general Public budgeting expenditure in GDP to measure the degree of government support. By introducing these control variables, we can more accurately analyze the impact of the digital economy on carbon emissions, eliminate interference from other factors, and improve the reliability of the results.

### 4.3. Descriptive Analysis of Variables

Considering the availability and completeness of the selected variable data, this article selects n major Yangtze River Delta cities with relatively complete data as the research objects. Except for -, the remaining data in the article mainly comes from the 2011-2020 China Urban Statistical Yearbook and various regional statistical yearbooks, and some missing values are supplemented using linear interpolation method. The descriptive statistics of the variables used are shown in Table 2.

**Table 2.** Descriptive Statistical Analysis of Variables

Variable	Sample size	Max.	Min.	Mean	S.D.	Variance
Dig	224	0.424	0.062	0.172	0.087	0.008
Pol	224	0.607	0.009	0.113	0.098	0.01
Ln in	224	11.148	9.794	10.518	0.314	0.099
Ln Ele	224	9.104	5.193	7.153	1.18	1.393
Ln Pop	224	7.292	4.301	6.046	0.621	0.386
Gov	224	0.283	0.076	0.14	0.05	0.003
Ln CE	224	9.432	4.613	6.879	1.072	1.148

## 5. Analysis of Empirical Results

### 5.1. Benchmark Regression Analysis

According to formula (1), Table 3 reports the benchmark regression results of the digital economy on urban carbon emission intensity.

**Table 3.** Benchmark Regression Analysis Results

Variable	Non standardized coefficient		Standardized coefficient	t	R <sup>2</sup>	Adjusted R <sup>2</sup>	F
	B	S.D.	Beta				
C	-0.158	1.812		-0.087	0.782	0.775	F=110.468, P=0.000***
Dig	4.248	0.620	0.344	6.848			
Pol	1.452	0.593	0.133	2.448			
lnIn	0.491	0.181	0.144	2.710			
lnEle	-0.256	0.077	-0.282	-3.304			
LnPop	0.549	0.064	0.318	8.592			
Gov	-5.971	0.833	-0.280	7.165			

Note: \*\*\*, \*\*, \* respectively represent significance levels of 1%, 5%, and 10%.

In Table 3, we report the benchmark regression results of the digital economy on urban carbon emission intensity and carbon emission efficiency. As shown in the table, the P-values of the six variables are all less than 0.05, and 1% shows significant significance at the horizontal level,

indicating that the above change factors have a significant impact on the suppression of carbon emissions.

The first column of regression results shows that the regression coefficient of the digital economy development index on carbon emission intensity is negative, and the regression coefficient on carbon emission efficiency is positive. Both have statistical significance at the 1% significance level. This indicates that the digital economy can effectively reduce the carbon emission intensity of cities and improve carbon emission efficiency, verifying the validity of the hypothesis.

In order to consider that the factors with endogenous variables may affect the consistency of the estimated parameters, the Instrumental variables estimation method is used to verify whether there is an endogenous problem. The results show that the LM statistic of Instrumental variables estimation is 18.835, which is significant at the 1% significance level, rejecting the assumption that Instrumental variables estimation is not identifiable; The F statistic is 110.468, which exceeds the critical value of the 10% significance level of the weak Instrumental variables estimation test, 16.38, and rejects the weak Instrumental variables estimation hypothesis. This shows that the endogeneity problem has been alleviated by using the Instrumental variables estimation method, and the estimated coefficient of the impact of the digital economy on carbon emission intensity and carbon emission efficiency is still significantly negative, thus proving the reliability of the benchmark regression conclusion.

## 5.2. Analysis of Intermediary Mechanism

From the benchmark regression analysis, it can be seen that the digital economy has a significant inhibitory effect on carbon emissions. Then we discuss the Mesomeric effect of the digital economy on carbon emissions, that is, whether changes in industrial structure can significantly inhibit carbon emissions at the same time.

According to formulas (2) and (3), if the coefficient  $\alpha_2$  is significant, and  $\beta_2$  and  $c_2$  are significant, which proves that there is a Mesomeric effect.

As shown in Table 4, we demonstrate the impact of the digital economy on industrial structure and carbon emissions. By observing the first column of Table 4, we can find that the digital economy has a significant positive impact on the upgrading of industrial structure, indicating that the development of the digital economy can enhance the level of industrial upgrading. Further combining the data in the second column, we can find that when the advancement of industrial structure is added as a variable to the impact of the digital economy on carbon emissions, the coefficient of influence of the development of the digital economy on carbon emissions decreases. At the same time, the upgrading of industrial structure has a significant impact on carbon emissions at a significant level of 1%, and the upgrading of each unit of industrial structure can reduce carbon emissions by 11.3%. This shows that the upgrading of industrial structure has a Mesomeric effect in the impact of digital economy development on carbon emissions.

According to the regression results in the third column, the development of the digital economy has a significant positive impact on the rationalization of industrial structure, at a significant level of 1%. This indicates that the development of the digital economy can improve the rationalization level of industries. In the fourth column, the impact of the digital economy on carbon emissions is negative, indicating a negative correlation between the development of the digital economy and carbon emissions. In addition, the rationalization coefficient of the industry is also negatively correlated at a significant level of 5%, and an increase in the rationalization of the industrial structure per unit can reduce carbon emissions by 0.6%. This confirms that the digital economy can reduce carbon emissions by improving the rationalization level of industrial structure.

**Table 4. Mesomeric effect**

Variable	Industrial upgrading		Industrial rationalization	
	Model (1) Iup	Model (2) lnCE	Model (4) Ira	Model (4) lnCE
Dig	0.389*** (3.50)	-0.156** (-2.56)	4.328 (2.89)	-0.172*** (-2.88)
Iup		-0.109** (-3.50)		
Ira				-0.005* (-2.43)
Constant	1.960** (0.88)	-2.891* (-1.23)	4.595 (1.33)	-3.862 (-1.58)
Control variable	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
N	224	224	224	224

Note: \*\*\*, \*\*, \* respectively represent significance levels of 1%, 5%, and 10%.

However, compared with the advanced industrial structure, the rationalization of industrial structure has a lower Mesomeric effect in the impact of digital economy development on carbon emissions. The possible reason is that with the advancement of the advanced industrial structure, more and more enterprises are turning to the Tertiary sector of the economy with low energy consumption, which directly affects the reduction of carbon emissions. The rationalization of industrial structure is a process of optimizing labor and material resources, and its adjustment speed is relatively slow, so its impact on carbon emissions is relatively mild.

## 6. Conclusion and Suggestions

### 6.1. Conclusion

In order to help achieve the dual carbon goals quickly, this article analyzes the impact of digital economy development on carbon emissions in the Yangtze River Delta urban agglomeration and draws the following conclusions:

- (1) The development of the digital economy can effectively empower carbon emissions reduction, have a significant inhibitory effect, and improve carbon emission efficiency.
- (2) Through the analysis of intermediary mechanisms, the development of the digital economy has driven the process of carbon reduction by leveraging both structural and technological effects. The development of the digital economy can significantly promote the upgrading of industrial structure, and achieve carbon emissions reduction by upgrading and rationalizing the industrial structure.

### 6.2. Suggestions

In terms of the direct impact of the digital economy on carbon emissions, the following policy measures can be taken to reduce carbon emissions:

- (1) Strengthen energy efficiency requirements. Develop and promote energy efficiency standards for digital devices, and promote manufacturers to produce more energy-efficient digital devices. Similarly, energy efficiency standards need to be established in data center operations, encouraging the use of energy-saving technologies and optimizing energy management to reduce energy consumption and carbon emissions.
- (2) Build a green data center. Promote the green construction of data centers, such as using renewable energy for power supply, adopting efficient and energy-saving computer room

design and equipment, etc. At the same time, by optimizing server virtualization and resource utilization, reduce the number of servers and energy consumption.

(3) Promote carbon neutral digital technology. Encourage the development of carbon neutral digital technologies, such as carbon neutral computing and data storage solutions, to reduce carbon emissions in data centers. At the same time, promote the research and application of low-power and high-efficiency computing devices and communication technologies.

In terms of the indirect factors of the digital economy on carbon emissions, in order to reduce carbon emissions, the following policy measures can be taken:

(1) Innovate and advocate for low-carbon products and services. Encourage innovation in the digital economy and promote the development of more environmentally friendly and low-carbon products and services. The government can establish an environmental innovation fund to support the research and promotion of low-carbon technologies and products.

(2) Develop low-carbon industries. The digital economy has driven the development of many emerging low-carbon industries. For example, the renewable energy industry, clean energy technology research and development, energy-saving and environmental protection products, etc. Through the application and innovation of digital technology, these industries can reduce carbon emissions during production and use, playing an important role in reducing global greenhouse gas emissions.

(3) Promote the development of resource Sharing economy. Encourage and support the resource Sharing economy to reduce resource waste and carbon emissions. The government can formulate policies and norms to support the development of the Sharing economy, and strengthen the supervision of the Sharing economy platform to ensure its compliant operation.

(4) Promote pragmatic low-carbon consumption. The digital economy provides convenient low-carbon consumption channels through online shopping, electronic payment, Sharing economy and other ways. People can reduce the demand for physical stores and reduce carbon emissions through online shopping. At the same time, the digital economy can also provide more information and visual data, convey information about low-carbon products and services to consumers, and guide and encourage the purchase of low-carbon products.

(5) Provide carbon reduction solutions. The digital economy provides carbon reduction solutions for various industries through innovative technologies and services. For example, the energy management system based on Big data and artificial intelligence can monitor and optimize energy consumption in real time and reduce carbon emissions. At the same time, the digital economy also supports the development of carbon emission reduction mechanisms such as Carbon emission trading, Carbon footprint calculation and carbon compensation.

In summary, the digital economy promotes the development of low-carbon industries, guides low-carbon consumption, and provides carbon reduction solutions by optimizing industrial structure, while promoting carbon reduction in traditional industries. These measures are of great significance for achieving sustainable development and addressing climate change. Governments, enterprises, and individuals all need to actively participate in promoting the sustainable development of the digital economy.

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## References

- [1] Beomsoo Kim. Virtual Field Experiments for a Digital Economy: A New Research Methodology for Exploring an Information Economy [J]. *Decision Support System*, 2002,32(1):215-231.

- [2] Carlsson B. The Digital Economy: what is new and what is not? [J]. *Structural Change and Economic Dynamics*, 2004, 15(3):245-264.
- [3] Ren Baoping, Sun Yixin. The Mechanism and Path for Cultivating New Advantages of High Quality Economic Development in China through the Digital Economy [J]. *Economic Perspective*, 2022 (4): 38-48.
- [4] Wang Kaike, Wu Guobing, Zhang Guijun. Has the development of the digital economy improved production efficiency? [J]. *Economist*, 2020 (10): 24-34.
- [5] Yang Wenpu. Digital Economy Promotes High Quality Development: Improving Production Efficiency and Expanding Consumption [J]. *Journal of Shanghai University of Finance and Economics*, 2022, 24 (1): 48-60.
- [6] Xie Yunfei. The impact effect and mechanism of digital economy on regional carbon emission intensity [J]. *Contemporary Economic Management*, 2022, 44 (2): 68-78.
- [7] Miao Junjun, Chen Jing, Fan Tianzheng, et al. Impact of digital economy development on carbon emissions -- based on Panel data analysis of 278 Prefecture-level city [J]. *Southern Finance*, 2022 (2): 45-57.
- [8] Li Zhiguo, Wang Jie. How does the development of digital economy affect spatial carbon emissions in the context of economic agglomeration? [J]. *Journal of Xi'an Jiaotong University (Social Science Edition)*, 2022, 42 (5): 87-97.
- [9] Zhang Jie, Fu Kui, Liu Bingrong. How the Digital Economy Empowers Urban Low Carbon Transformation: From the Perspective of Dual Goal Constraints [J]. *Modern Finance and Economics (Journal of Tianjin University of Finance and Economics)*, 2022 (8): 3-23.
- [10] Shao Shuai, Xu Le, Zhang Shaoyi. Can carbon Emissions trading help achieve the "double carbon" goal -- Evidence of heterogeneity from the energy supply and consumption sides [J]. *Journal of Lanzhou University (Social Sciences Edition)*, 2022 (4): 27-40.