

The Digital Economy and Urban Carbon Reduction

Qizhong Zheng *

School of Economics and Management, Xi 'an Shiyou University, Xi 'an 710300, China

* Corresponding Author Email: qiz.zheng@outlook.com

Abstract. As an important tool for high-quality development, the digital economy plays a key role in the low-carbon transformation of Chinese cities and implementing the "double carbon" strategy. This paper attempts to systematically examine the effects and impact mechanisms between the digital economy and carbon emissions at theoretical and empirical levels. Using panel data from 282 prefecture-level cities in China from 2011 to 2019, we analyze the impact of the digital economy on urban carbon emissions and its mechanisms of action using panel data econometric models and mediating effects. The findings show that the digital economy significantly reduces urban carbon emissions, and this conclusion still holds after a series of robustness tests, and the positive effects of the digital economy become more and more obvious over time; the digital economy can promote carbon emission reduction by optimizing the industrial structure of cities and strengthening the introduction of foreign investment. These findings confirm that the beneficial effects of the digital economy have been extended to social welfare, providing a useful reference for sustainable economic and environmental development. At the same time, the Chinese government should increase its efforts to build digital infrastructure, expand the application of digital technology and improve the industrial structure to contribute to China's low-carbon development. The research in this paper advances a deeper understanding of carbon emission reduction and the effects, mechanisms, and stages of carbon reduction driven by the digital economy.

Keywords: Carbon Neutral; Digital Economy; Carbon Emission Reduction; Green Innovation; Industrial Structure Upgrading.

1. Introduction

Since the second half of the 20th century, the world's industrialization activities have seriously affected natural ecology. The global economy's steady growth in recent years has increased corporate demand for energy sources such as electricity and oil. The development and use of fossil energy sources such as electricity production, oil, and natural gas will contribute to rising global temperatures. In the last 50 years, atmospheric carbon dioxide levels have been 27% higher than they have been in the previous 650,000 years, and global carbon dioxide emissions have risen by almost 50%; the summer of 2022 has seen extreme heat events in many countries in the northern hemisphere and rare hot weather in the Antarctic and Arctic. The accumulation of small human activities has largely altered the Earth's new natural systems, propagating through the planet's ecosystems in complex mechanisms that have irreversibly changed the human environment. At the same time, the relationship between humans and the environment has also undergone fundamental changes, which not only affect the basis of human existence but also have a direct impact on the modernization process of our country, for which it is urgent to promote low-carbon development (China Academy of Information and Communication Research, 2021). In its Sixth Assessment Report Working Group III report, the Intergovernmental Panel on Climate Change (IPCC) stated that global greenhouse gas emissions would need to peak by 2025 and be reduced by 43% by 2030 to meet the 1.5 below target agreed in the 2015 Paris climate agreement (IPCC, 2022). To address climate change, reduce domestic carbon emissions and energy consumption, and achieve systemic economic and social change, China has set the strategic goals of achieving carbon peaking by 2030 and carbon neutrality by 2060. Achieving carbon peaking and carbon neutrality is the path to new human development. At present, the promotion and application of carbon labeling and other technologies in China have made certain achievements in terms of energy saving and emission reduction by enterprises and the

promotion of low-carbon consumption by consumers. However, there is still a long way to go to achieve carbon neutrality and peaking. (Huang, J.Y., et al. 2023).

As proposed in the G20 Initiative on Digital Economy and Development Cooperation, the digital economy is a series of economic activities in which digitized information and knowledge are key factors of production, and modern information networks are an important carrier. The effective use of information and communication technologies is an important driving force for efficiency improvement and economic structure optimization. Since the 20th century, with technologies like cloud computing, artificial intelligence, and blockchain. The digital economy plays an increasingly important and positive role in developing the real economy. The integration and development of digital technology with various industries have empowered industrial innovation, enabling the development of new business models and modes in our market, one after another. At the same time, the digital economy is an important driving force for the formation of a virtuous cycle in international trade, and international cooperation in the digital economy has been deepening, focusing on three areas: digital infrastructure, digital trade, and digital economy and trade (Xu Ming, 2023). In recent years, countries along the "Belt and Road" have accelerated their digital economy infrastructure and promoted digital transformation to stimulate sustained economic development (Xing Shaosi, 2022); International cooperation also creates a good international environment for the development of China's digital economy and improves the domestic environment for digital economy innovation (Wang Feng et al., 2022). Since the spread of the new crown epidemic around the world, the continued expansion of the size of the global digital economy has contributed significantly to easing the downward pressure on the global economy. As of 2021, the size of the digital economy in 47 major economies worldwide is US\$38.1 trillion, of which China's digital economy is the second largest, reaching US\$7.1 trillion (China Academy of Information and Communication Research, 2021). The digital economy has gradually become an important part of the global economy and a sustainable driving force for the healthy development of our economy.

In recent years, the environmental improvement effect of the digital economy has received more and more attention, and the development of the digital economy has brought new opportunities for carbon emission reduction. In its 2023 White Paper on the Synergistic Development of Greening and Digitalisation, the China Communications Institute mentioned the synergistic development of greening and digitalization, which connotes that digitalization empowers greening and greening pulls digitalization. The core elements of the digital economy are the digitization of industry and the industrialization of digital, both of which have become two irreversible trends in the development of society today. Industrial digitization is upgrading various aspects of the traditional industrial chain using digital technology against the background of the successful development of digital technology, emphasizing the use of digital technology to run and manage enterprises. Accelerating the integration of digital technology and the real economy has become a consensus. Industrial digitization will significantly increase enterprises' data collection capacity and speed and improve the efficiency of green technology innovation. At the same time, industrial digitization will help enterprises' business models to be constantly iterated and updated, creating greater social value (Lin Yan, 2023). The digitalization of industry will also place greater demands on companies' capabilities to develop new technologies and capabilities that will help them remain competitive and dynamic in the digital world (CEFIS, E et al., 2023). Digital industrialization is the process by which emerging technologies are transformed into digital products through results and gradually industrialized (Liu and Dong et al., 2023). Through the application of digital products, digital industrialization has improved the efficiency of various links in the industrial chain, provided enterprises with more accurate and high-quality market forecasts, reduced design costs and manufacturing costs, promoted industrial structure upgrading, and improved business efficiency. On the other hand, digital industrialization has given rise to several new industries, promoted digital technology innovation, and provided technical support for reducing urban carbon emissions (Liu & Dong, 2023). The real economy has become an important place for digital technology application and innovation, and the integration of digital technology and the real economy is supporting the rapid development of the digital economy.

The existing literature on the digital economy can be broadly divided into two parts: research on the connotation and extension of the digital economy and the quantification of its scale and research on the relationship between the digital economy and other socio-economic development variables (Xu Xianchun et al., 2020; Wang Jun et al., 2021; Zhang Xun et al., 2019). In the research on carbon emission reduction, on the one hand, there is a large body of literature that directly analyses the impact of environmental policies and regulations on carbon emissions (Dong Zhiqing et al., 2021); on the other hand, most studies also focus on trade openness, foreign investment introduction, industrial structure upgrading and adjustment, regional economic integration (Zhao, Yuhuan, et al. 2022; Guo, Yi, et al. 2022; Mao, Xiyan, et al. 2022) The influence of factors such as carbon emissions and carbon intensity on carbon emissions. Finally, some other scholars have studied carbon emissions' spatial and temporal evolution characteristics (Wang Shaojian et al., 2021).

At present, digital technology is becoming an important driving force in "resolving the conflict between economic development and environmental pollution." Some scholars believe that the carbon emission reduction effect of the digital economy is more obvious in the central and western regions and regions with high carbon emission intensity and that the carbon emission reduction effect of digital industrialization is more significant than that of industrial digitization (Xie Yunfei, 2022). Another group of scholars argues that the negative impact of digital economy development on carbon emissions reduction is stronger in the East, with urban agglomerations in inner-city regions being more affected (Xu Weixiang et al., 2022). Although the research on the digital economy and carbon emissions reduction has yielded some results, there is a paucity of literature on direct empirical testing of the relationship between digital economy development and carbon emissions and its mechanisms at the city level (Guo Feng et al., 2022). Given this, the marginal contribution of this paper lies in three aspects: firstly, it measures the level of development of the digital economy and the level of carbon emissions, respectively, and constructs a system of indicators and a benchmark model for the corresponding empirical analysis. Secondly, it provides a detailed theoretical analysis of the intrinsic mechanisms of the digital economy affecting urban carbon emissions and a comprehensive assessment of the role of the digital economy in achieving carbon neutrality, broadening the existing literature. Thirdly, this paper examines the robustness of the digital economy on urban carbon emissions in a multi-dimensional manner and identifies and examines the mechanisms of the digital economy's effect on carbon emissions reduction in a step-by-step manner to provide some reference for subsequent research in this area.

2. Literature Review and Theoretical Hypotheses

In the context of the national strategy of carbon peaking and carbon neutrality, the role of the digital economy in reducing urban CO₂ emissions has received unprecedented attention from academics. Current academic research on the digital economy and carbon emissions has gathered in the following areas: First, with the advent of the digital economy, the digital economy has reshaped the way of value co-creation among various innovation agents, built an innovation-oriented digital innovation ecosystem and a digitally empowered innovation ecosystem, and promoted innovation in products, technologies, and services (Chao Zhang et al., 2021). Digital industry development, digital innovation capabilities, and inclusive digital finance effectively reduce carbon emissions and growth rates (Zhang Qingyan et al., 2022). First, digital industrialization and industrial digitization through digital empowerment of various industrial technology upgrades will generally achieve carbon emission reduction and promote the development of low-carbon transformation in China (Yi Ziyu et al., 2022). Secondly, the development of the digital economy has significantly raised the level of technological innovation and green technological innovation, indirectly reducing carbon emission levels through digitally empowered green innovation power and green eco-efficiency (Guo Feng, 2022; He Maobin et al., 2021; Kong Lingzhang et al., 2022), At the same time, the increase in urban green innovation output reflects the greater role of digital inclusion in small and medium-sized cities with high levels of marketization (Westhwaite et al., 2022). Finally, digital finance acts on carbon

emission reduction through the entrepreneurial, innovation, and industrial upgrading effects (Xu, Zhao, et al., 2021). Based on the above analysis, research hypothesis 1 is proposed.

Hypotheses 1 (H1) *The digital economy effectively contributes to the reduction of carbon emissions in cities.*

With the widespread application and comprehensive penetration of digital technology in the industrial field, it can significantly improve the operational efficiency of industrial organizations, thus accelerating the transformation and upgrading of traditional industries and leading to the formation and development of new industries. As a result, the proportion of industries will be changed, labor productivity will be increased, the proportion of output value in industries with high labor productivity will be expanded, the overall industrial structure will be transformed in the direction of intelligence and greening, and the level of industrial structure will be improved. (Li Zhiguo, et al. 2021). The transformation and upgrading of industrial structure is an important intermediary mechanism through which the digital economy acts to reduce carbon emissions. The digital economy contributes to achieving the "double carbon" target. It promotes the growth of total factor productivity in cities by optimizing the industrial structure, alleviating information asymmetry and resource mismatch, and reducing the external diseconomies of carbon emissions. (He Maobin, 2021; Hu Yi, et al, 2022). In addition, the development and optimization of the IT industry significantly reduce carbon emissions in the central and eastern regions, and the digital economy as a moderating variable can weaken the negative impact of a structure dominated by non-renewable energy consumption on carbon emissions (LI, Y et al., 2021). The upgrading of industrial structure is not only of practical significance for the rational allocation of resources between industrial sectors at various stages of the industrial chain but also improves the efficiency of the use of regional resource factors, reduces energy consumption per unit of product, and thus reduces carbon emissions per unit of product (YU, Y et al., 2018). Based on the above analysis, research hypothesis 2 was formulated.

Hypotheses 2 (H2) *The digital economy has a positive effect on reducing urban carbon emissions by promoting the upgrading of urban industrial structures.*

3. Indicator Construction, Data Sources and Identification Strategies

3.1. Indicator Construction

3.1.1. Selection of Dependent Variable

Approach to accounting for carbon emissions from energy consumption based on the IPCC report (CHENG, Y, et al., 2014), We obtained the total provincial carbon emissions based on the energy consumption data records of each industry, using the total energy consumption of each type, the respective standard coal conversion factors, and the product of carbon emission factors. The city-level carbon emissions were then obtained through an inverse model based on the existence of a significant positive association between nighttime lighting brightness values and carbon dioxide emissions (ZHU, J, et al., 2019).

3.1.2. Selection of Independent Variables

With the widespread application and comprehensive penetration of digital technology in the industrial field, it can significantly improve the operational efficiency of industrial organizations, thus accelerating the transformation and upgrading of traditional industries and leading to the formation and development of new industries. As a result, the proportion of industries will be changed, labor productivity will be increased, the proportion of output value in industries with high labor productivity will be expanded, the overall industrial structure will be transformed in the direction of intelligence and greening, and the level of industrial structure will be improved. (Li Zhiguo, et al. 2021). The transformation and upgrading of industrial structure is an important intermediary mechanism through which the digital economy acts to reduce carbon emissions. The digital economy contributes to achieving the "double carbon" target. It promotes the growth of total factor productivity in cities by optimizing the industrial structure, alleviating information asymmetry and resource

mismatch, and reducing the external diseconomies of carbon emissions. (He Maobin, 2021; Hu Yi, et al, 2022). In addition, the development and optimization of the IT industry significantly reduce carbon emissions in the central and eastern regions, and the digital economy as a moderating variable can weaken the negative impact of a structure dominated by non-renewable energy consumption on carbon emissions (LI, Y et al., 2021). The upgrading of industrial structure is not only of practical significance for the rational allocation of resources between industrial sectors at various stages of the industrial chain but also improves the efficiency of the use of regional resource factors, reduces energy consumption per unit of product, and thus reduces carbon emissions per unit of product (YU, Y et al., 2018). Based on the above analysis, research hypothesis 2 was formulated.

3.2. Model Design

$$CO2_{it} = \alpha_0 + \alpha_1 dige_{it} + \alpha_2 X_{it} + \delta_t + \varepsilon_{it} \tag{1}$$

Where CO2 is the carbon emissions of the city i in period t and the digit is the level of digital economic development of i in period t. To address the disturbance of endogeneity problems caused by omitted variables, this paper introduces control variables, individual fixed effects, time fixed effects, and random error terms, whose vector Zit represents population density (pnd), expressed as the ratio of the total population to the area of the city region at the end of the year. Foreign investment openness (fdi), is measured as the ratio of FDI to GDP of the city in which it is located. Financial development (fin), is measured as a ratio of loans from financial institutions to GDP. Energy efficiency (energy), is measured as GDP per 10,000 tonnes of standard coal—transport facilities adequacy (Trans).

3.3. Data Sources and Descriptive Statistics

This paper uses 282 prefecture-level cities in China from 2011 to 2019 as the research sample, and the relevant data are obtained from the China Urban Statistical Yearbook and other databases. The descriptive statistics of each indicator are shown in the table below. In order to prevent the influence of the magnitude and outliers on the accuracy of the regressions, this paper treats some variables with a magnitude transformation, some variables with a logarithmic treatment, and all variable values with a 1% tail reduction at both ends.

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
<i>dige</i>	2538	11.021	0.920	8.053	15.014
<i>co2</i>	2538	1.344	0.076	0.670	2.502
<i>nlight</i>	2538	1.890	0.989	-1.355	4.112
<i>energy</i>	2538	0.163	0.007	0.140	0.187
<i>pnd</i>	2538	5.746	0.916	1.629	7.968
<i>trans</i>	2538	1.575	4.461	0.061	90.678
<i>fdi</i>	2538	0.017	0.017	0.000	0.192
<i>fin</i>	2538	1.561	3.294	0.025	44.898

4. Empirical Analysis

4.1. Baseline Regression

Table 1 reports the results of the baseline regression tests. Column 1 reports the results of the regression of the but-for variable on urban carbon emissions for the integrated digital economy development index with individual and time bivariate fixed effects, with the regression coefficient of urban carbon emissions (CO2it) being -0.014 and significant at the 5% level; column 2 reports the results of the regression after adding population density (pnd) as a control variable, with the regression coefficient of urban carbon emissions (CO2it) is -0.015 and significant at the 5% level; column 3 reports the regression results after increasing foreign investment openness (fdi) as a control variable,

and the regression coefficient of urban carbon emissions (CO2it) is -0.014 and significant at the 5% level; column 4 reports the regression results after increasing the degree of financial development (fin) as a control variable, and the regression coefficient of urban carbon emissions (CO2it) The regression coefficient for CO2it is -0.014 and is significant at the 5% level; column 5 reports the regression results after adding energy efficiency as a control variable and the regression coefficient for CO2it is -0.016 and is significant at the 1% level; column 6 reports the regression results after adding transportation facilities as a control variable and the regression coefficient for CO2it is -0.016 and is significant at the 1% level; column 6 reports the regression results after adding transportation facilities as a control variable and the regression coefficient for CO2it is -0.014 and is significant at the 5% level. The regression coefficient for urban carbon emissions (CO2it) is -0.016, significant at 1%. The estimated coefficients for the digital economy in all six columns of data in Table 1 are significantly negative, and in terms of economic implications, the regression results in column 6 show that when the digital economy development index rises by one unit, the level of urban carbon emissions decreases in an average sense by 0.016. Therefore, the regression indicates that the degree of digital economy development has a significant negative relationship with the intensity of urban carbon emissions, and hypothesis 1 of this paper is tested.

With the inclusion of control variables, both the degree of foreign investment openness and energy use efficiency passed the significance test with carbon emissions, indicating a significant negative relationship with urban carbon emissions. Specifically, cities with greater openness to foreign investment and higher energy efficiency have lower levels of urban carbon emissions. This empirical result verifies hypothesis 2.

Table 2. Return to baseline.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>dige</i>	-0.014** (0.006)	-0.015** (0.006)	-0.014** (0.006)	-0.014** (0.006)	-0.016*** (0.006)	-0.016*** (0.006)
<i>pnd</i>		0.011 (0.028)	0.011 (0.028)	0.011 (0.028)	0.004 (0.028)	0.004 (0.028)
<i>fdi</i>			-0.383** (0.155)	-0.383** (0.155)	-0.442*** (0.156)	-0.448*** (0.156)
<i>fin</i>				-0.000 (0.002)	0.001 (0.002)	0.001 (0.002)
<i>energy</i>					-3.857*** (1.264)	-3.921*** (1.270)
<i>trans</i>						-0.001 (0.002)
<i>constant</i>	1.503*** (0.064)	1.440*** (0.172)	1.443*** (0.172)	1.444*** (0.172)	2.132*** (0.283)	2.142*** (0.284)
<i>City FE</i>	Yes	Yes	Yes	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	2538	2538	2538	2538	2538	2538
<i>adj. R²</i>	0.089	0.088	0.090	0.090	0.093	0.093

Note: () values are robust standard errors; ***, **, * denote results passing significance tests at 1%, 5% and 10% confidence levels respectively.

4.2. Robustness Analysis

Based on the previous regressions, the following robustness tests were conducted in this paper:

Replacement of the digital economy measure. In the previous paper, the digital economy was measured using the principal component method, and here in this paper, we refer to the method of Zhou, Lei, and Gong (2022)(Zhou Lei et al., 2022); using the entropy method, a comprehensive development index for the digital economy is obtained through objective weighting, denoted as *dige2*.

Alternative carbon emission measures. This paper calculates the carbon emissions of 255 typical cities in China, recorded as CO22, based on the carbon emissions inventory of Chinese cities

compiled by the China Carbon Accounting Database (CEADs) sponsored by the National Natural Science Foundation of China, the UK Science and Technology Research Council, CEADs and other domestic and international professional bodies and research institutions.

Table 2 reports the regression results of robustness tests for replacing the explanatory and explanatory variables measures. Columns 1 and 2 report the regression results after replacing the explanatory variables: Column 1 reports a regression coefficient of -0.254 for urban carbon emissions (CO2) with individual and time bivariate fixed effects, which is significant at the 1% level; column 2 reports a regression coefficient of -0.279 for urban carbon emissions (CO2) after introducing all control variables, which is significant at the 1% level Columns 3 and 4 reports the regression results after replacing the explanatory variables: column 3 reports a regression coefficient of -3.627 for urban carbon emissions (CO2) with both individual and time fixed effects, which is significant at the 1% level; column 4 reports a regression coefficient of -3.446 for urban carbon emissions (CO2) after introducing all control variables, which is significant at the 1% level. Significant.

The estimated coefficients for the digital economy and the integrated digital economy development index in Table 2 are all significantly negative, both pass the significance test at the 1% level, and the model fit is good. When comparing the regression results with the baseline regression results, none of the significance of the impact of the digital economy on urban carbon emissions has changed substantially. The regression results, therefore, continue to support the base regression findings, suggesting that accelerating the development of the digital economy is strategically important in promoting carbon-neutral action for carbon peaking.

Table 3. Robustness tests.

	(1)	(2)	(3)	(4)
	co2	co2	co2_ceads	co2_ceads
<i>dige2</i>	-0.254*** (0.072)	-0.279*** (0.074)		
<i>dige</i>			-3.627*** (1.054)	-3.446*** (1.064)
<i>pnd</i>		0.000 (0.028)		-1.983 (4.681)
<i>fdi</i>		-0.400** (0.157)		17.100 (26.405)
<i>fin</i>		0.002 (0.002)		-0.522* (0.280)
<i>energy</i>		-4.422*** (1.281)		496.046** (222.534)
<i>trans</i>		-0.001 (0.002)		0.181 (0.892)
<i>_cons</i>	-0.652 (0.566)	-0.122 (0.607)	80.882*** (11.702)	10.116 (48.876)
<i>City FE</i>	Yes	Yes	Yes	Yes
<i>Year FE</i>	Yes	Yes	Yes	Yes
<i>N</i>	2538	2538	2295	2295
<i>adj. R²</i>	0.091	0.096	0.927	0.928

Note: () values are robust standard errors; ***, **, * denote results passing significance tests at 1%, 5% and 10% confidence levels respectively.

5. Conclusions and Insights

This paper explores the impact of the digital economy on urban carbon emissions and its mechanism of action, based on the policy context of China's 'double carbon' target, using urban panel data from 2011 to 2019 and introducing control variables, combining individual fixed effects, time fixed effects and random error terms. The main findings are as follows: First, the development of the digital economy does have a significant emission reduction effect, which can strongly support the

achievement of carbon neutrality and carbon peaking in China, and this conclusion still holds after adopting robustness tests such as the substitution variable method. Second, the digital economy has a positive effect on reducing urban carbon emissions by promoting the upgrading urban industrial structures.

The findings of this paper have the following implications: First, we should continue to strengthen the research and development and iterative updating of digital technologies in the field of carbon neutrality and carbon peaking and incorporate the development of the digital economy into the strategy of carbon neutrality and carbon peaking, to help to green with digitalization. At the same time, we should step up the construction of digital infrastructure, use digital technology to help energy-consuming industries improve resource use efficiency, realize industries' digital transformation, and promote green development on the ground. Second, deepen the integration of the digital economy with the real economy, continuously promote the upgrading of urban industrial structures, and play its intermediary role in promoting the further reduction of urban carbon emissions. Broaden the path for the digital economy to improve urban carbon emissions and bring into play the green value of the digital economy while also allowing the digital economy to empower traditional industries, thereby promoting sustainable development.

References

- [1] China Academy of Information and Communication Research. White paper on the development of China's digital economy [M]. Beijing: China Academy of Information and Communication Research, 2021.
- [2] Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Z]. Panel on Climate Change [Z]. Cambridge: Cambridge University Press, 2022.
- [3] Huang JY, Liu SJ. 2023. International experience and China's strategy in promoting the application of carbon labels [J]. *Reform*, (02): 62-74.
- [4] Xu M. 2023. Study on the path of promoting international cooperation in China's digital economy under the new development pattern [J]. *Journal of Qilu Studies*, (1): 133-142.
- [5] Xing Shaosi. 2022. Research on digital economy cooperation in countries along the "Belt and Road" [J]. *Economic Review*, (01): 46-51.
- [6] Wang Feng, GAO Changhai, Zhang Sen. 2022. The inner logic and practical path of international cooperation to promote innovation in digital economy [J]. *Journal of Beijing Administrative College*, (4): 80-87.
- [7] China Academy of Information and Communication Research. White paper on the global digital economy [M]. Beijing: China Academy of Information and Communication Research, 2021.
- [8] Lin Yan. 2023. Measurement and analysis of coupling and coordination between industrial digitalization and green technology innovation [J]. *China Circulation Economy*, 37(2): 68-78.
- [9] Cefis E, Leoncini R, Marengo L, Montesor S. 2023. Firms and innovation in the new industrial paradigm of the digital transformation [J]. *Industry and Innovation*, 30(1): 1-16.
- [10] Liu and Dong, Ji Ran. 2023. Study on the mechanism and effect of digital economy for industrial structure upgrading [J]. *Science and Technology Progress and Countermeasures*, 40(1): 61-70.
- [11] Xu Xianchun, Zhang Meihui. 2020. A study on measuring the size of China's digital economy: an international comparison perspective [J]. *China Industrial Economy*, (05): 23-41.
- [12] Wang J, Zhu J, Luo X. The development level of China's digital economy. 2021. Measuring the development level and evolution of China's digital economy [J]. *Quantitative, economic and technical economic research*, 38(7): 26-42.
- [13] Zhang Xun, Wan Guanghua, Zhang Jiajia, He Zongyue. 2019. Digital economy, financial inclusion and inclusive growth [J]. *Economic Research*, 54(08): 71-86.
- [14] Dong Zaqing, Wang Hui. 2021. An examination of the effectiveness of market-based environmental regulation policies: empirical evidence from the perspective of carbon emissions trading policies [J]. *Statistical Research*, 38(10): 48-61.

- [15] Zhao Yuhuan, Qian Zhiling, Xu Xin. 2022. The impact of China's industrial structure upgrading on carbon emissions in the context of carbon peaking and carbon neutrality [J]. *Exploring Economic Issues*, (3): 87-105.
- [16] Guo Yi, Cao Xianzhong, Wei Wendong, Zeng Gang. 2022. Study on the impact of regional integration of the Yangtze River Delta on urban carbon emissions [J]. *Geographical Studies*, 41(1): 181-192.
- [17] Mao Xiyan, He Canfei, Wang Peiyu, Xu Rui, Hu Xingmuzi, He Shuqi. The impact of import and export trade of environmental products on carbon emissions in China [J]. *Journal of Natural Resources*, 37(5): 1321-1337.
- [18] Wang Shaojian, Xie Zihan, Wang Zehong. 2021. Spatial and temporal evolution of carbon emissions in Chinese counties and the influencing factors [J]. *Journal of Geography*, 76(12): 3103-3118.
- [19] Xie Yunfei. The effect of digital economy on regional carbon emission intensity and its mechanism of action [J]. *Contemporary Economic Management*, 44(2): 68-78.
- [20] Xu Weixiang, Zhou Jianping, Liu Chengjun. 2022. Spatial effects of digital economy development on urban carbon emissions [J]. *Geographical Studies*, 41(1): 111-129.
- [21] Guo Feng, Yang Shangguang, Ren Yi. 2022. Digital economy, green technology innovation and carbon emissions: empirical evidence from Chinese cities [J]. *Journal of Shaanxi Normal University (Philosophy and Social Science Edition)*, 51(03): 45-60.
- [22] Zhang Chao, Chen Kaihua, Mu Rongping. 2021. Digital innovation ecosystem: theoretical construction and future research [J]. *Research Management*, 42(03): 1-11.
- [23] Zhang Qingyan, Li Yuxin. 2022. Study on the impact of digital economy on carbon emissions in China [J]. *Financial theory and practice*, 43(5): 146-154.
- [24] Yi Ziyu, Wei Long, Wang Lei. 2022. Study on the effect of technological development of digital industry on carbon emission intensity [J]. *International economic and trade exploration*, 38(4): 22-37.
- [25] He Maobin, Yang Xiaowei. 2021. Digital inclusive finance, carbon emissions and total factor productivity [J]. *Financial Forum*, 26(02): 18-25.
- [26] Kong, Lingzhang, Li, Jinye. 2022. The impact of digital economy development on the efficiency of China's green economy [J]. *Economic system reform*, (06): 67-73.
- [27] Wei, Shiwei, Du, Jinmin, Pan, Shuang. 2022. How the digital economy promotes green innovation - empirical evidence from Chinese cities [J]. *Finance and Economics Series*, (11): 10-20.
- [28] Xu Zhao, GAO Yu, Huo Zhifang. 2021. Pollution reduction effects of digital finance [J]. *Finance and Economics Science*, (4): 28-39.
- [29] Li ZG, Che SH, Wang J. 2021. Digital economy development and industrial structure transformation and upgrading--a test of heterogeneity based on 275 cities in China [J]. *Journal of Guangdong University of Finance and Economics*, 36(05): 27-40.
- [30] Hu Yi, Jin Shuchang. 2022. Digital technology helps to achieve the goal of "double carbon": theoretical mechanism and practical path [J]. *Journal of Finance and Accounting*, (06): 111-118.
- [31] Li Y, Yang X, Ran Q, Wu H, Irfan M, Ahmad M. 2021. Energy structure, digital economy, and carbon emissions: evidence from China [J]. *Environmental Science and Pollution Research*, 28(45): 64606-64629.
- [32] Yu Y, Deng Y, Chen F. 2018. Impact of population aging and industrial structure on CO2 emissions and emissions trend prediction in China [J]. *Atmospheric Pollution Research*, 9(3): 446-454.
- [33] Cheng Y, Wang Z, Ye X, Wei Y D. 2014. Spatiotemporal dynamics of carbon intensity from energy consumption in China [J]. *Journal of Geographical Sciences*, 24 (4): 631-650.
- [34] Zhu J, Fan Y, Deng X, Xue L. 2019. Low-carbon innovation induced by emissions trading in China [J]. *Nature communications*, 10(1): 4088.
- [35] Zhao T, Zhang Z, Liang SG. 2020. Digital economy, entrepreneurial activity and high quality development - empirical evidence from Chinese cities [J]. *Management World*, 36(10): 65-76.
- [36] Zhou Lei, Gong Zhimin. 2022. The enhancement effect of digital economy level on green and high quality development of cities [J]. *Economic Geography*, 42(11): 133-141.