Proceedings of the 8th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/130/2024.19874

Examining the Role of the Digital Economy in Enhancing Pollution Control and Carbon Reduction Efficiency Across 30 Provinces

Aiting Huang[1,a,*], Jiaqi Liang[1,b]

[1]*College of Economics and Management, Xinjiang University, Tianshan District, Urumqi, Xinjiang Uygur Autonomous Region, 0991830000, China*
a. 1440086925@qq.com, b. 2749232167@qq.com
**corresponding author*

Abstract: This research investigates how the digitalized economy influences pollution levels and carbon abatement efficiency, utilizing panel data from 30 provinces in China spanning the years 2012 to 2022. Using a single research framework, this analysis merges the impacts of environmental pollution and carbon output, applying the entropy method to establish indicators assessing the digitalized economy and efficiency in pollution and carbon abatement. Applying a fixed effects model, this study empirically investigates the digitalized economy's influence on pollution levels and carbon abatement efficiency. The results indicate that advancements in each province's digitalized economy markedly enhance the effectiveness of carbon abatement and pollution management. This is achieved through three key strategies: digital transformation of enterprises, consumer digital upgrading, and government digital governance. Moreover, regional advancements in pollution control and carbon abatement efficiency occur irrespective of the stage of digitalized economy development.

Keywords: Digital economy, Pollution and carbon abatement efficiency, Entropy method, Fixed effects model.

1. Introduction

China's ecological environment is currently facing severe challenges. Key issues in the development of a green ecosystem today include enhancing resource efficiency to reduce carbon output, restructuring the energy system to cut carbon, geological storage of carbon, ecosystem carbon sequestration, and achieving precise, scientific, and law-based pollution control. The "Air Pollution Prevention and Control Action Plan," popularly known as the "Ten Measures for Air," was enacted by the State Council in 2013, which underscored the importance of comprehensive strategies to reduce emissions from multiple pollutants. It also set stringent admission criteria for high-pollution, high-energy-consuming industries and established specific pollutant discharge standards. The "Three-Year Action Plan for Winning the Blue Sky Defense Battle," introduced in 2018, stresses that only by expediting energy structural reforms can a low-carbon, efficient, and clean energy system be realized. In 2021, the "Opinions on Further Advancing the Battle for Pollution Prevention and Control" underscored the need to promote peak carbon initiatives and drive green, low-carbon development. With the Central Committee led by President Xi Jinping prioritizing ecological

DOI: 10.54254/2754-1169/130/2024.19874

protection, China saw remarkable advancements from 2013 to 2021. The emissions of critical pollutants in exhaust gases, such as particulate matter, nitrogen oxides, and the sulfur dioxide levels were cut down considerably—from 20.44, 22.27, and 12.78 million tons to 2.75, 9.73, and 5.38 million tons, respectively. PM2.5 concentrations dropped by 57%, achieving outstanding results. China's commitment to pollution reduction is steadfast, as is its determination to pursue a green and low-carbon path. The country has recently enacted multiple policies focused on reaching carbon peak and carbon neutrality objectives, such as the 'Dual Carbon Energy Initiative,' 'Energy Conservation and Carbon Reduction Initiative,' 'Industrial Carbon Peak Initiative,' 'Urban-Rural Dual Carbon Initiative,' 'Circular Economy Carbon Reduction Initiative,' 'Low Carbon Technology Innovation Initiative,' 'Carbon Sink Enhancement Initiative,' and the 'National Low Carbon Initiative.' These measures have made substantial progress toward China's 'dual carbon' objectives.

Despite significant progress in reducing pollutants and carbon output, the journey toward a fully green, low-carbon ecological environment remains unfinished. The "Implementation Plan for Synergistic Pollution Reduction and Carbon Reduction Efficiency" was released in 2021 by the Ministry of Ecology and Environment in collaboration with the National Development and Reform Commission. This marked the first instance where the coordinated improvement of air quality and carbon peak goals in air pollution management was given explicit priority. As a result, reducing pollution and carbon output has become essential for boosting environmental governance and advancing a green transition throughout society. These efforts are essential steps in China's journey toward building an ecological civilization.

Notably, the digitalized economy has substantially contributed to environmental progress in achieving the 'dual carbon' objectives, effectively lowering carbon emission intensity [1-3]. It also reduces various pollutants in cities [4-6]. As a result, both pollution control and carbon abatement are achieved. By merging digital innovations such as big data and artificial intelligence with environmentally sustainable industries, the digitalized economy continues to improve resource allocation efficiency and drive productivity gains. Due to its broad applicability, high innovation potential, and significant reach, the digitalized economy now plays a vital role in fostering eco-construction and supporting low-carbon development aligned with "dual carbon" goals. Therefore, it has become particularly urgent to study how the digitalized economy affects the efficiency of pollution control and carbon abatement.

2. Literature Review

Scholars worldwide have recently focused on investigating the link between the digitalized economy and pollution and carbon abatement, with research generally categorized as follows.

On the one hand, a variety of scholars have explored the core attributes of the digitalized economy. Zhang Xueling and Chen Fang identified essential factors for improving the quality of China's digitalized economy development, such as enhancing digital infrastructure, driving advancements in information technology, and promoting policies that encourage scientific innovation [7]. Wang Binyan and others highlighted that the growth of the digitalized economy is affected by factors such as technological advancements, economic development stages, market openness, and industrial structure, each playing a distinct role [8]. Liu Pingfeng and Zhang Wang noted that as the modularization of digital technology accelerates, the ease of use, diffusion, and technological extensibility of digital technologies have increased, significantly reducing market transaction costs [9].

On the other hand, as the 14th Five-Year Plan advances, finding a balance between ecological protection and economic development has become a central focus in building a new green ecosystem. Pollution and carbon abatement have become vital levers for deepening environmental governance and fostering high-quality development. Many scholars have also conducted studies on pollution and

DOI: 10.54254/2754-1169/130/2024.19874

carbon abatement. Yu Guangbin, Zhang Zhengzhi, and Ding Yingying emphasized the need to control emissions of pollutants and greenhouse gases, ensure data sharing, and improve energy efficiency [10]. Xiong Huawen argued that the pathway to synergistic pollution and carbon abatement lies in energy transition, with priority on conservation and dual control of energy intensity and consumption [11]. Li Haisheng, Xie Minghui, Li Xiaomin, and Li Bin suggested that there is no need to build new systems but instead to incorporate carbon abatement requirements into the existing ecological and environmental protection system. They proposed integrated planning for pollution and carbon abatement at the decision-making stage, with strengthened oversight throughout project construction, emphasizing carbon abatement assessments and clean legislation [12].

A review of existing literature reveals that the majority of scholars investigate how the digitalized economy influences pollution reduction or carbon abatement, frequently approaching these effects from one perspective. The intersection of the digitalized economy, pollution, and carbon abatement has been underexplored in the context of an integrated framework. This research investigates how the digitalized economy influences the effectiveness of pollution control and carbon emission reduction. Based on panel data from 30 provinces in China (2012–2022), the paper provides an empirical analysis of its effects on environmental outcomes.

3. Research Mechanism

Three channels can be used to investigate how the digitalized economy influences pollution and carbon abatement effectiveness: government digital governance, corporate digital transformation, and consumer digital upgrading. Government, enterprises, and consumers respectively enhance pollution and carbon abatement efficiency by improving digital monitoring and management capabilities, promoting technological innovation and industrial upgrading, and fostering green consciousness.

Firstly, from a governmental perspective, digital governance has the potential to improve the efficiency of pollution control and carbon abatement. On one side, advancements in digital technologies such as big data, artificial intelligence, blockchain, and advanced algorithms, offer governments innovative tools, solutions, and platforms within the framework of the digitalized economy. Cloud computing can be applied to dynamically monitor pollutant and carbon output, allowing the government to move beyond traditional regulatory models and providing technical support for measuring urban pollutant and carbon output. Based on empirical research on 223 cities, Fan Hejun[13] found that digital regulation enables "carbon profiling," significantly enhancing the government's monitoring and management capacity. Su Chunhong's[14] study using the DEA-Tobit model found that the digitalized economy enhances government efficiency through talent, capital, and innovation. Additionally, Ren Baoping's[15] research indicates that digital technologies improve government decision-making accuracy, governance efficiency, and investment effectiveness. Moreover, the "network effect" of the digitalized economy can address information asymmetry. Dong Yu[16] noted that the "network effect" created by digital technology can overcome barriers to information flow, thus empowering government governance[17] and enhancing government management and monitoring capabilities, ultimately promoting pollution and carbon abatement.

From the viewpoint of enterprises, the development of the digitalized economy facilitates low-carbon development in high-carbon industries by introducing advanced green technologies, equipment, and facilities, which increase production efficiency and flexibility, thereby reducing carbon output and improving pollution control. Li Xiaolu[18] highlighted that the digitalized economy fosters green technological innovation, a crucial factor for enabling low-carbon development within enterprises. Hu Delong's [19] empirical research utilizing data from listed companies from 2011 to 2020 shows that the digitalized economy fosters regional innovation, thereby improving total factor productivity in enterprises. Hu Haifeng's [20] research on how the digitalized economy influences enterprise transformation and upgrading revealed that digital technologies

DOI: 10.54254/2754-1169/130/2024.19874

improve resource allocation, thereby increasing the probability of successful innovation. Thus, technologies of the digitalized economy, including big data, cloud computing, artificial intelligence, blockchain, and advanced algorithms, drive green technological innovation within enterprises, contributing to reductions in pollution and carbon output. Additionally, the digitalized economy promotes market-based factor allocation, facilitating industrial restructuring. Long Yunan [21] empirically confirmed that the digitalized economy supports the restructuring of industrial systems by enhancing the energy, financial, and consumer sectors. Liu Hedong [22] showed that the digitalized economy drives industrial transformation and upgrading through matching, intelligent, and derivative effects.

From a consumer standpoint, the digitalized economy can, on one hand, encourage a transition away from traditional consumption models, fostering a shift toward green consumption. The rise of the internet has given way to a variety of online consumption platforms, significantly reducing environmental pollution and energy consumption caused by travel. Shi Hongjing [23] pointed out that the digitalized economy has the capacity to promote green consumption. In addition, Ban Nannan [24] identified a U-shaped correlation between the digitalized economy and residential carbon output by applying a spatial econometric model, emphasizing the role of the digitalized economy in promoting residential carbon output reduction. On the other hand, with the internet's development, residents have more direct and convenient access to information on environmental pollution, which easily cultivates a "crisis awareness," leading to a spontaneous green consciousness and a proactive attitude toward environmental protection.

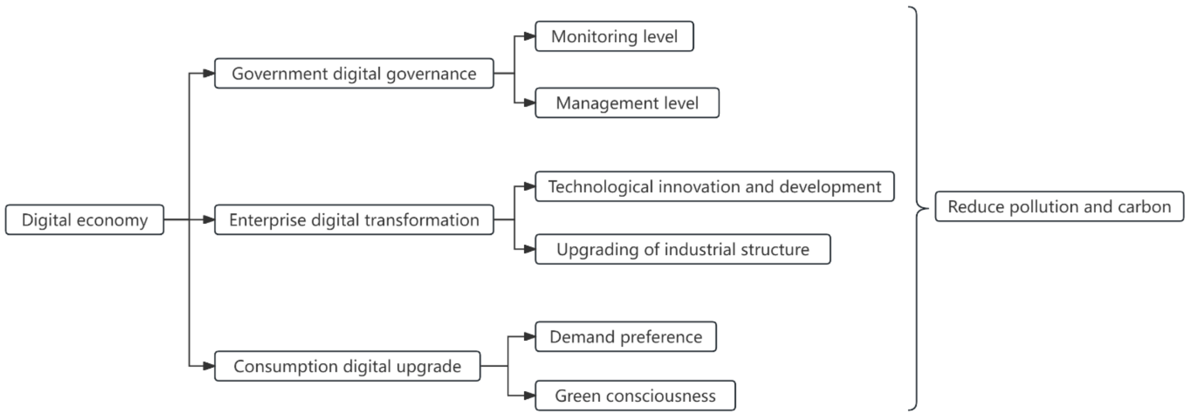

Figure 1: Research Mechanism Diagram

4. Research Methodology

4.1. Construction of the Baseline Model

The baseline model outlined below has been developed to comprehensively assess the impact of the digitalized economy on pollution control and carbon abatement:

$$\ln cp_{it} = \alpha + \beta \ln dig_{it} + \gamma X_{it} + \varepsilon_{it}$$

Where i denotes the region, t represents the year, $\ln cp_{it}$ is the pollution and carbon abatement evaluation indicator level, $\ln dig_{it}$ refers to the digitalized economy evaluation indicator level, X_{it} represents control variables, and α, β and γ denote the constants, coefficients for the digitalized economy indicators, and control variable indicators, respectively. ε_{it} denotes the error term.

DOI: 10.54254/2754-1169/130/2024.19874

4.2. Design of Digital Economy Indicators

Encompassing a wide array of economic activities, the digitalized economy relies on digital information and knowledge as key production inputs, facilitating quick information flow and accelerating economic processes. Based on the previous research by Zhao Tao [25] and Wang Jun [26], the indicators for the digitalized economy are constructed as presented in Table 1.

Table 1: Digital Economy Indicator Design

Primary Indicators	Secondary Indicators	Description of Secondary Indicators	Attribute
Digital Infrastructure	Internet Penetration	Broadband internet access points	Positive
		Broadband internet users	Positive
		Internet domain registrations	Positive
	Mobile Phone Penetration	Density of mobile phone base stations	Positive
		Mobile phone penetration rate	Positive
	Information Transmission Scope	Long-distance optical cable length per unit area	Positive
Digital Industrialization	Software and IT Services Industry	Ratio of software revenue to GDP	Positive
		Employees in information transmission, software, and IT services	Positive
	Electronic Information Manufacturing Development	Ratio of IT service revenue to GDP	Positive
		Ratio of total telecommunications business to GDP	Positive
		Per capita telecommunications business volume	Positive
	Postal Industry Development	Per capita postal business volume	Positive
		Volume of express deliveries	Positive
		E-commerce transaction volume for enterprises	Positive
Industrial Digitization	Enterprise Digitalization	Proportion of enterprises engaged in e-commerce activities	Positive
		Number of computers per 100 employees	Positive
		Number of websites per 100 enterprises	Positive
	Digital Financial Inclusion	Digital financial inclusion index	Positive
Digital Innovation Capacity	Research and Innovation Capacity	Full-time equivalent of R&D personnel in industrial enterprises	Positive
		R&D expenditure in industrial enterprises	Positive
		Number of R&D projects in industrial enterprises	Positive
		Number of patents granted	Positive
		Value of technology contracts	Positive

DOI: 10.54254/2754-1169/130/2024.19874

4.3. Design of Pollution and Carbon Reduction Indicators

Pollution and carbon abatement entail the concurrent decrease of environmental pollutants and greenhouse gas emissions, embodying a crucial approach for promoting green, low-carbon development in the 21st century. Drawing on Zhang Xuechun[27] and other relevant studies, the following comprehensive evaluation indicator system for pollution and carbon abatement has been developed:

Table 2: Pollution and Carbon Reduction Indicators

Primary Indicators	Secondary Indicators	Unit	Attribute
Pollution Reduction System	Sulfur dioxide emissions	10,000 tons	Positive
	PM2.5 concentration	10,000 tons	Positive
Carbon Reduction System	Carbon dioxide emissions	10,000 tons	Positive

4.4. Selection of Control Variables

To mitigate potential error bias, a set of variables that could influence the dependent variable are incorporated. These factors include: Government Intervention (gov), measured by the ratio of provincial fiscal expenditure to GDP; Economic Development Level (gdp), indicated by GDP per capita; Infrastructure (inf), represented by the ratio of provincial road area to GDP; and Foreign Investment (inv), which is gauged by the ratio of actual foreign capital utilization to GDP.

5. Empirical Analysis

5.1. Overall Distribution of the Digital Economy

Table 3 shows that from 2012 to 2022, the level of digitalized economy development across provinces grew consistently each year, experiencing a notable dip in 2020 before gradually recovering. Nationwide, the digitalized economy displays a distinct upward trajectory. The regions are grouped as: the eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region covers Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; the western region encompasses Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang; and the northeast region is represented by Liaoning, Jilin, and Heilongjiang. According to Table 3, the Eastern region has a significantly more advanced digitalized economy compared to other regions, followed by the Central, Western and Northeastern regions. On a national scale, the digitalized economy level rose significantly from 0.061 in 2012 to 0.164 in 2022, demonstrating China's steady progress in digitalized economy development.

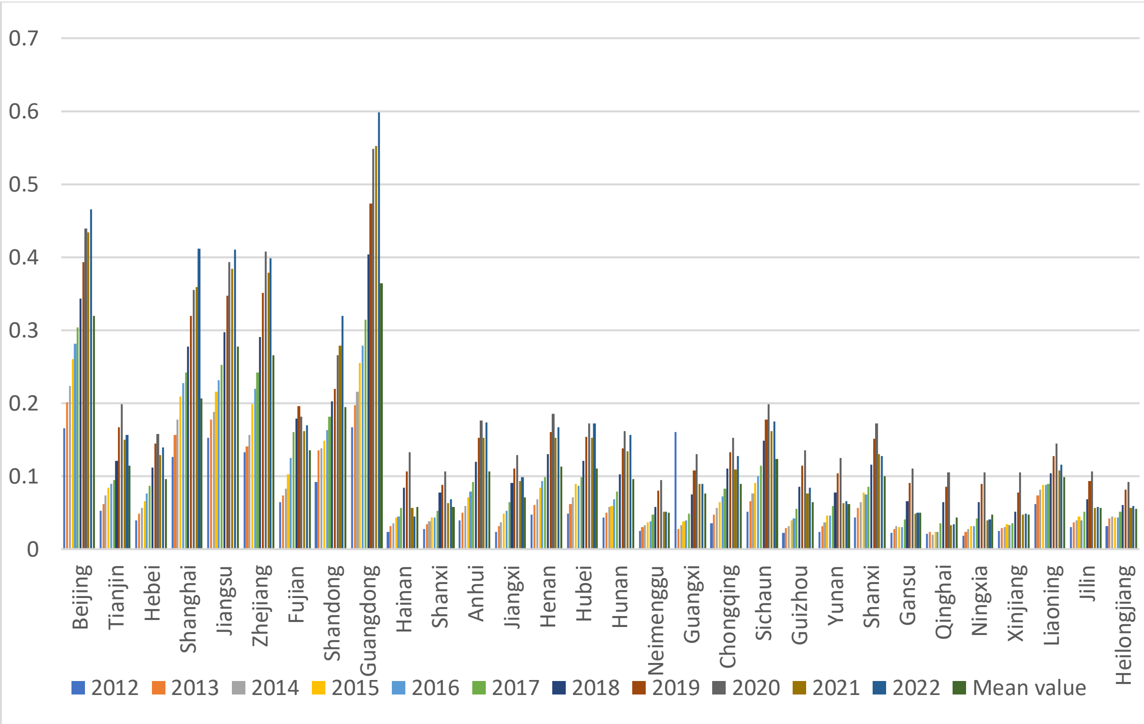

Figure 2: Overall Distribution of the Digital Economy.

5.2. Overall Distribution of Pollution and Carbon Reduction

As shown in Table 4, from 2012 to 2022, the national pollution and carbon abatement index gradually increased, rising from 0.298 in 2012 to a peak of 0.382 in 2021, followed by a slight decline. Overall, the national pollution and carbon abatement index displays an upward trend. Regionally, the eastern region has the highest average pollution and carbon abatement index, followed by the northeastern, central, and western regions, respectively.

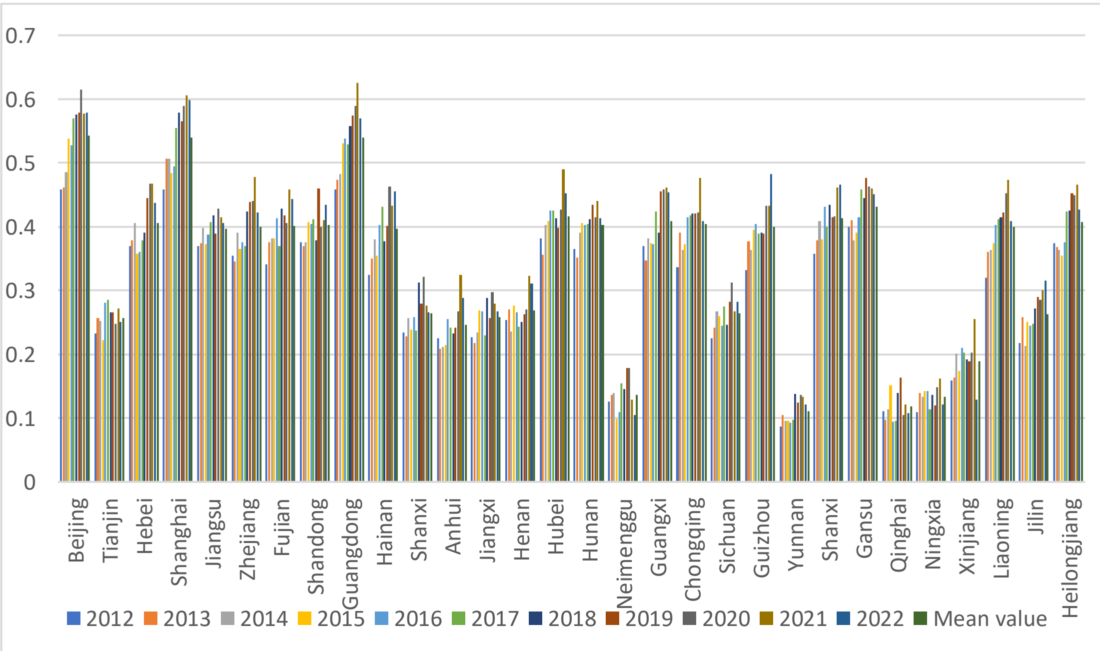

Figure 3: Overall Distribution of Pollution and Carbon Reduction.

DOI: 10.54254/2754-1169/130/2024.19874

5.3. Baseline Regression Results Analysis

As shown in Table 3, Model (1) presents the regression results using the OLS method, Model (2) shows the results after removing control variables and using a fixed effects model, Model (3) includes control variables in the fixed effects model, and Model (4) replaces the foreign investment control variable with the investment level. The findings show a strong positive correlation between the digitalized economy and regional pollution and carbon abatement, consistent across both the OLS method and the fixed effects model. When control variables are added, the positive relationship remains unchanged. For robustness testing, control variables are replaced in Model (4), and the empirical results continue to support the conclusion that the digitalized economy promotes pollution and carbon abatement.

Table 3: Baseline Regression Results.

	(1)	(2)	(3)	(4)
InDig	0.940***	0.028***	0.115*	0.083*
	(8.48)	(15.37)	(2.49)	(1.66)
Constant	0.849***	0.288***	-0.191*	-0.132
	(5.31)	(80.76)	(-2.38)	(-1.34)
Control Variables	YES	NO	YES	YES
Time Fixed Effects	NO	YES	YES	YES
Individual Fixed Effects	NO	YES	YES	YES
R^2	0.443	0.370	0.211	0.173

Note: *, *, *** indicate statistical significance at 10%, 5%, and 1% levels, respectively, with t-values in parentheses.

6. Conclusion and Recommendations

Utilizing data from 30 Chinese provinces over the period from 2012 to 2022, this study adopted the entropy method to evaluate comprehensive indicators reflecting each province's digitalized economy, as well as their pollution and carbon abatement efforts. Based on this evaluation, a fixed effects model was employed for empirical analysis, which demonstrated that the digitalized economy plays a substantial role in advancing regional pollution control and carbon abatement. This positive impact occurs through three primary pathways: government digital governance, corporate digital transformation, and consumer digital advancement. In light of these findings, the following recommendations are suggested:

(1) Focus on Enhancing Government Digital Governance: By improving digital management capabilities, the government can foster pollution and carbon abatement. Setting digital reform as an overarching goal, the government should advance transformations within the ecological sector, developing a smart, digitalized ecological environment system for monitoring, early warning, tracking, and rectification. Implementing a "one-source-one-file" one-on-one approach to pollution source management will allow for comprehensive government digital governance.

(2) Encourage Corporate Digital Transformation Initiatives: To promote market reform and drive industrial upgrading, companies should advance “Five-in-One” strategies, emphasizing innovation, digitalization, efficiency, intelligence, and low carbon. Supporting companies with subsidies for technological innovation will comprehensively drive the green and low-carbon transformation of industrial structures.

DOI: 10.54254/2754-1169/130/2024.19874

Funding: This research was supported by the National College Student Innovation Training Program project, "The Impact of the Digital Economy on Pollution and Carbon Reduction: Theoretical Mechanisms and Empirical Research."

References

[1] Li, Y., & Jiang, Q. (2023). Analysis of the carbon abatement effect of the digitalized economy: A dual-path analysis based on production and consumption. Journal of Nanjing Audit University, 20(4), 81–90.

[2] Qu, S., Shi, D., & Yang, D. (2022). China's digitalized economy carbon output: Total measurement and trend outlook. China Population, Resources and Environment, 32(9), 11–21.

[3] Jiang, S., & Jia, F. (2023). How does the digitalized economy promote carbon abatement? An examination based on urban carbon intensity and carbon efficiency. Survey World, (1), 14–21.

[4] Zhu, Y., & Yang, H. (2023). Research on the impact of the digitalized economy on environmental pollution emissions. Environmental Science and Management, 48(9), 168–173.

[5] Deng, R., & Zhang, A. (2022). Research on the impact and mechanism of China's urban digitalized economy development on environmental pollution. Southern Economy, (2), 18–37.

[6] Li, G., & Zhou, X. (2021). Can promoting the digitalized economy improve environmental pollution in China? A quasi-natural experiment based on the "Broadband China" strategy. Macroeconomic Research, (7), 146–160.

[7] Zhang, X., & Chen, F. (2018). Research on the quality and influencing factors of China's digitalized economy development. Productivity Research, (6), 67–71.

[8] Wang, B., Tian, J., Cheng, L., Hao, F., Han, H., & Wang, S. (2018). Spatial differentiation and influencing factors of China's digitalized economy. Scientia Geographica Sinica, 38(6), 859–868.

[9] Liu, P., & Zhang, W. (2021). How does digital technology empower total factor productivity in manufacturing? Studies in Science of Science, 39(8), 1396–1406.

[10] Yu, G., Zhang, Z., & Ding, Y. (2021). Exploring pollution and carbon abatement pathways in industrial parks under carbon peak and carbon neutrality targets. Low Carbon World, 11(6), 68–69.

[11] Xiong, H. (2022). Research on the energy transition pathway for synergistic pollution and carbon abatement. Environmental Protection, 50(1), 35–40.

[12] Li, H., Xie, M., Li, X., & Li, B. (2022). Constructing an integrated system for synergistic pollution and carbon abatement across the entire process. Environmental Protection, 50(1), 24–29.

[13] Fan, H., Pan, N., & Wu, T. (2023). Research on the carbon abatement effect of digitalized economy development: An empirical test based on 223 prefecture-level cities. Journal of Beijing Technology and Business University (Social Science Edition), 38(3), 25–38.

[14] Su, C., & Li, Z. (2023). Has the digitalized economy improved government public service capacity? Modern Economic Research, (1), 1–14.

[15] Ren, B., & Sun, Y. (2023). Research on the coordination of institutional innovation between government and market under the digitalized economy background. Research on Financial and Economic Issues, (4), 3–13.

[16] Dong, Y., Yuan, X., & Zha, Y. (2024). Carbon emission trading, digitalized economy, and total factor productivity of enterprises. Business Research, (1), 12–22.

[17] Hu, C., & Mao, F. (2023). Digital technology empowering government governance: Digital infrastructure and economic resilience. Journal of Hebei University of Economics and Business, 44(4), 40–52.

[18] Li, X., Li, X., & Zhang, W. (2023). Digital economy, dual-track intellectual property protection, and enterprise green technology innovation. China Business and Market, 37(7), 78–91.

[19] Hu, D., & Chao, W. (2023). Regional innovation, digitalized economy, and enterprise total factor productivity. Modern Economic Research, (9), 62–72.

[20] Hu, H., Wei, T., & Wang, A. (2023). Research on the impact and mechanism of the digitalized economy on enterprise transformation and upgrading. Journal of Humanities, (8), 33–45.

[21] Long, Y., Kong, D., & Huang, Y. (2023). Research on the influence mechanism and countermeasures of the digitalized economy promoting industrial structure upgrading: Analysis based on energy structure, financial structure, and household consumption structure. Research on Science Management, 41(1), 80–89.

[22] Liu, H., & Ji, R. (2023). Mechanism and effect of the digitalized economy promoting industrial structure upgrading. Science & Technology Progress and Policy, 40(1), 61–70.

[23] Shi, H., & Chen, L. (2023). Pathways for the digitalized economy to drive green consumption development. Ecological Economy, 39(5), 118–122.

[24] Ban, N., & Zhang, X. (2023). Impact of the digitalized economy on China's household consumption carbon output. China Environmental Science, 43(12), 6625–6640.

[25] *Zhao, T., Zhang, Z., & Liang, S. (2020). Digital economy, entrepreneurial activity, and high-quality development: Evidence from Chinese cities. Management World, 36(10), 65–76.*
[26] *Wang, J., Liu, X., & Zhu, J. (2023). Can the digitalized economy promote high-quality regional economic development? China Soft Science, (1), 206–214.*
[27] *Zhang, X., Cao, X., & Song, L. (2023). Measurement and influencing factors of China's pollution and carbon abatement efficiency: Based on the super-efficiency SBM-Tobit model. Ecological Economy, 39(10), 174–183.*