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Original Paper

Digital Economy and Carbon Neutral Technological Innovation

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Abstract
To achieve sustainable development, improve global competitiveness, promote ecological civilization building, and ease economic transition and upgrading, carbon neutral technical innovation is essential. This paper examines the effect with panel data from 270 Chinese from 2006 to 2022, as well as multidimensional heterogeneity analysis. The conclusions are as follows. (1) Digital economy can promote carbon neutral technological innovation. (2) The mechanism test demonstrates how scientific and technological production and regional innovation potential might contribute to carbon neutral technology innovation in the digital economy. (3) Heterogeneity analysis shows that based on the three-dimensional city attributes of "location-feature-scale", the research results show significant differences across different cities. The research conclusions provide a certain reference value for further strengthening and promoting carbon neutral technology innovation.

Keywords
Digital economy, Carbon neutral technological innovation, Mediating effect model

1. Introduction

One of the biggest challenges to human progress is the changing global climate, which poses a serious threat to human society everywhere (Liu et al., 2025a). The IPCC assessment states that global warming must be limited to 1.5° C in order to avoid serious harm. A coordinated worldwide effort to lower greenhouse gas emissions and advance carbon neutrality will be required to achieve this goal. The European Union, as one of the leaders of the international community, has taken the lead in announcing absolute reduction targets. To promote global climate governance, several pertinent policies and measures have also been enacted by China. The "dual carbon" goal, first put up by China in 2020, is to peak carbon dioxide emissions before 2030 and achieve carbon neutrality by 2060 (Zhang et al., 2021). One of the primary strategies for achieving carbon neutrality is the development of carbon capture, utilization, and storage (CCUS) technology. Through carbon neutral technology innovation, improving carbon capture efficiency, reducing carbon capture cost, and finding safer and more effective ways of carbon storage, we can immediately lower the atmospheric concentration of carbon dioxide and provide carbon emission reduction solutions for industries and fields that are difficult to reduce emissions.

The digital economy is becoming the main driver of economic growth in the modern period, progressively displacing the industrial and agricultural economies. Since data is the main component of manufacturing and the powerful force behind digital technologies, it has sped up the creation of carbon neutral technology and created a new production method (Zhu & Lu, 2024). Artificial intelligence, 5G, and other technological advancements have been made in China since 2023. The digital economy’s industrial system has improved, the data factor market has grown more quickly, and the economy’s overall factor productivity has increased and consolidated. This has helped China's new, high-quality productive forces to grow and accumulate. The digital economy has ability to break down traditional industrial barriers and promote global cooperation in a few areas, such as energy and artificial intelligence. Enterprises, scientific research institutions, and talents in different fields exchange and cooperate, integrate their superior resources, jointly solve the problem of carbon neutrality technology, and promote technological innovation.

This is the rest of the paper: The literature is surveyed in the second section to find relevant studies on the development of carbon-neutral technologies and the digital economy. The mechanism analysis and research hypotheses of this work are elaborated in the third section. The research strategy is covered in Section 4. The empirical test, the fifth component, confirms the theoretical theory. Lastly, a discussion of the research results and policy recommendations rounds up the report.

2. Literature Review

2.1 Relevant Research on the Digital Economy

Studies of the digital economy's effects provide the basis of most of the current study on it. In terms of the quality of jobs, encouraging digital industrialization can boost the labor market. In addition to fostering a general increase in employment quality, numerous new career opportunities have resulted from this (Ding et al., 2024). From the perspective of household consumption, new consumption categories and forms have emerged because of the digital economy. By making internet purchasing more convenient, reducing liquidity issues, and boosting non-agricultural jobs and entrepreneurship, it can raise inhabitants' consumption levels (Ji et al., 2024). The digital economy affects carbon emissions through three paths: trade openness, financial development, and government governance efficiency (Li et al., 2024). According to Xu et al. (2025), the digital economy is a new economic form that is fueled and enabled by digital technology. As such, it has emerged as a significant means of fostering the growth of new qualitative productive forces from the standpoint of innovation and entrepreneurship. More specifically, Huang et al. (2025) believed that the digital economy, as an important engine of economic growth, is bringing new opportunities for the improvement of entrepreneurship, guiding entrepreneurs to better grasp the opportunities, and providing support for innovation and entrepreneurship. Lou et al. (2024) claim that with innovative infrastructure investment, innovative financial resources, and innovative human resources, the digital economy can significantly promote the improvement of business innovation quality.

2.2 Relevant Research on Carbon Neutral Technology Innovation

To achieve net zero emissions and balance carbon emissions with carbon sequestration, a variety of technologies and approaches known as carbon neutral technologies are intended to decrease, trap, or offset greenhouse gas emissions. These technologies are widely used in energy, industry, transportation, agriculture, and other fields. The examination of carbon neutral technological innovation and its affecting elements is the primary focus of the research that is currently available on the subject. As for the carbon neutral technology innovation itself, by using a dual logic for selecting significant carbon neutral technologies, Zhao and Li (2021) examined the economic viability of carbon neutral technology from the standpoints of cost-benefit and green premium. They also talked about the technology's risk and macro-impact. In the process of carbon neutral technology innovation, the legal system plays an extremely key role, playing multiple functions of guidance, guarantee, and coordination in an all-around way. Feng (2024) accompanies carbon neutral technology innovation from many angles and channels, based on the institutional building of carbon neutral technology innovation and the functional positioning of law in this area. On the one hand, the government should play a macro-control role, and policy plays a key guiding role in carbon neutral technological innovation. By formulating relevant policies, the government clarifies the direction and focus of technological innovation, and guides enterprises and research institutions to increase R&D investment, thus promoting technological innovation (Gong & Xiao, 2024). However, as the primary source of technological innovation, businesses' autonomous investment is crucial to the development of carbon-neutral technology. According to market demand and their development strategies, companies should invest more in research and development of carbon neutral technologies and carbon capture and storage (CCS) (Liu et al., 2025b).

The research still must be improved, according to the findings: First, the impact of the digital economy on innovation and entrepreneurship, low-carbon environmental protection, household consumption, and employment quality is the primary focus of scholarly research on the subject. Its effects on carbon neutral technical innovation are not fully revealed. Second, most current research ignores the impact path on carbon neutral technological innovation from the dynamic perspective of the digital economy, instead concentrating on the innovation itself and the macro policy perspective. Third, much of the literature currently available on the digital economy makes recommendations at the macro level without fully addressing the notable variations in cities' resource endowment and geographic location from the standpoint of innovation capacity and scientific and technological output.

Thus, the following is the possible marginal contribution of this paper: First, digital economy's level is linked with carbon neutral technological innovation, and the deep relationship between the two is explored, which deepens the research on carbon neutral technological innovation. Second, from the perspectives of innovation capability and scientific and technical output, this study examines the effects of the digital economy's "black box" on the development of carbon-neutral technologies. Finally, based on the three-dimensional urban heterogeneous attributes of "location-feature-scale", the goal of the heterogeneity test is to fully pinpoint regional differences in the level of technological innovation that is carbon neutral in the digital economy.

3. Research Hypothesis

3.1 Direct Impact Mechanism and Research Hypothesis

The idea behind sustainable development is that to meet current needs without jeopardizing the ability of subsequent generations to meet their own, social progress, environmental protection, and economic expansion must be combined. This theory provides direction guidance for carbon neutral technological innovation and makes it clear that technological innovation should serve long-term ecological, economic, and social sustainability. In actuality, the development of renewable energy technology contributes to lowering carbon emissions, protecting the environment, and lessening reliance on conventional fossil fuels. Furthermore, it can stimulate the growth of associated industries, generate job opportunities, and support the social economy's sustainable development (Wang et al., 2025). On the one hand, accurate energy production, transmission, distribution, and use is possible with digital technologies like big data and the Internet of Things. Data on equipment energy usage can be collected through sensors and then analyzed by big data to find energy waste points and energy-saving potential, helping enterprises optimize production processes, decrease carbon emissions, and increase energy efficiency. On the other hand, cloud computing and high-performance computing technologies provide strong computing support for the carbon neutral technologies. Large-scale climate model simulations and the development of carbon-neutral technologies, like carbon capture and new energy storage materials, can be accelerated by scientific research institutes using cloud computing platforms.

As a result, this paper proposes hypothesis 1: Digital economy helps directly promote China's carbon neutral technology innovation.

3.2 Indirect Transmission Mechanism and Research Hypotheses

3.2.1 Analysis of the Mediating Effect of Scientific and Technological Output

By creating input-output tables, the input-output theory examines the link between the input and output of different economic sectors and reveals the inherent connections and laws governing economic activity. This hypothesis can be used to examine the quantitative link between scientific and technical output in the realm of science and technology. The degree to which scientific and technology input contributes to science and technology output, as well as the interdependence between various science and technology areas, can be measured by creating an input-output model. The growth establishes a basis for the strategies and plans for scientific and technological development, aids in the logical distribution of scientific and technological resources by the government and businesses, and assesses the impacts of scientific and technological policies. The government can choose to increase capital investment in the field of carbon neutral scientific research based on the findings of input-output analysis. This will help to increase scientific and technological output and economic benefits while also encouraging the development of carbon neutral technological innovation.

As a result, this paper proposes hypothesis 2: Digital economy can indirectly promote China’s carbon-neutral technological innovation by improving the level of scientific and technological output.

3.2.2 Analysis of the Mediating Effect of Regional Innovation Capability

According to the paradigm of technical innovation, technological innovation is the primary engine that propels social and economic advancement. The introduction of a "new combination" of production circumstances and elements or the development of a new production function that has never been employed in the production system before are examples of innovation. According to Tian et al. (2025), technological innovation that is carbon neutral can lower carbon emissions, increase energy efficiency, promote the shift to low- and zero-carbon energy and industries, and generate new economic values and social benefits. Because the digital economy allows businesses to buy technology and information at a lower cost, they can more quickly comprehend the market need for carbon-neutral technologies and their cutting-edge dynamics, allowing them to conduct technological innovation activities with greater accuracy. At the same time, digital platforms provide opportunities for enterprises to communicate and cooperate with global peers, promote knowledge sharing and technology diffusion, stimulate the innovation vitality of enterprises, and promote the research and development of carbon neutral technologies.

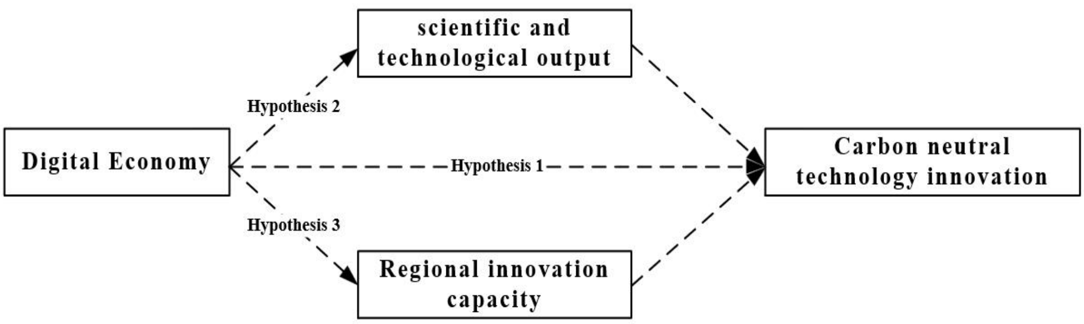

Figure 1. Framework of Theoretical Hypotheses

As a result, this paper proposes hypothesis 3: By enhancing regional innovation capacity, the digital economy can indirectly support China's development of carbon-neutral technologies.

4. Research Design

4.1 Model Construction

This study includes two-way fixed effects to address the issue of missing variables to investigate how the digital economy affects technological innovation that is carbon neutral. The benchmark regression model constructed is as follows:

$$gt_{it} = \alpha_0 + \alpha_1 digital_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{1}$$

Where and represent region and time respectively, represents urban carbon neutral technological innovation, represents the development degree of digital economy, a set of control factors called influences technological innovation that is carbon neutral, represents individual fixed effects, The time-fixed effect is denoted by γ_t, is the random error term. The calculated coefficient is in the equation above. It indicates that the digital economy fosters technological innovation that is carbon neutral if it is beneficial and noteworthy.

Furthermore, from the perspectives of regional innovation and scientific and technical output, this study provides intermediate features to assess the internal mechanism. If β_2, β_3, and in the model are all significant, then the mediating effect exists. Furthermore, according to the sign relationship between β_2, and β_3, partial mediation, masking effect, or complete mediation effect can be distinguished. If β_2, and have the same sign, it is a partial mediating effect. Otherwise, it is the masking effect. The mediating effect model is set as follows:

$$gt_{it} = \alpha_0 + \beta_1 digital_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{2}$$

$$M_{it} = \alpha_0 + \beta_2 digital_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{3}$$

$$gt_{it} = \alpha_0 + \beta_3 digital_{it} + \beta_4 M_{it} + \alpha_2 X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{4}$$

4.2 Variable Choice and Data Description

4.2.1 Explained Variable

Carbon neutral technological innovation (gt) is the variable that is being explained. The number of combined Patent Classification (CPC) Y02 patent applications used in this paper as a measurement index of carbon neutral technical innovation, drawing on the work of Cao and Su (2023). To find the carbon neutral technology patents that prefecture-level and higher cities applied for between 2006 and 2022, this article uses the instruction search approach.

4.2.2 Primary Explanatory Variable

The digital economy ($digital$) is the primary explanatory factor. This study evaluates the digital economy from two angles: Internet development and digital inclusive finance, using the methods of Liu et al. (2020). Four indicators are used to measure the development of the Internet, according to Chen et al. (2024): mobile phone penetration rate, relevant output, relevant employees, and Internet penetration rate. The “China Digital HP Financial Index”, developed in partnership with Ant Financial and Peking University's Institute of Digital Finance, is used in this study to quantify digital financial inclusion. The digital economy development index is then determined using the principal component analysis method.

4.2.3 Mediating Variable

Scientific and technological output ($technology$). Given that the more money spent on science and technology, the more funds’ enterprises will invest in carbon neutral technological innovation. This study cites Cao and Su’s (2023) practice and measures it using the ratio of spending on research and technology to spending in the local finance general budget. Regional innovation capacity ($innovation$). There are greater uncertainties and instability since the number of patents awarded must be tracked down and annual fees paid, whereas the number of patents gained is more transparent, timely, and accurate. Like Li (2007), this paper uses the regional patent applications’ logarithm to show regional innovation capabilities.

4.2.4 Control Variables

To ensure the validity of the results, the following control variables were selected for this study based on prior research: Industrialization Level ($manu$). This study makes references to Xiong and Wang’s (2024) research and measures it by dividing the GDP by the secondary industry’s added value. Service level ($serv$). Referencing Xiong and Wang’s (2024) research, this study measures it using the tertiary industry's added value to GDP ratio. Government size ($govern$). This study makes references to Wang et al. (2020) and measures it using the government budget spending to regional GDP ratio. Population density (pop). The population/urban area at the end of the year is represented numerically in this publication, which is based on research by Zhang et al. (2023).

In light of the issue of unavailable and missing data, this study excludes Hong Kong, Macao, Taiwan, and a few other cities with incomplete data before choosing panel data from 270 prefecture-level Chinese cities. We used linear interpolation to fill in the missing data points. Table 1 displays the findings of the descriptive statistics for the variables.

Table 1. Descriptive Statistical Results of Main Variables

Variable	Sample	Mean	SD	Min	Max
gt	4590	1.68	0.83	0	4.65
technology	4590	0.02	0.02	0	0.21
innovation	4590	3.2	0.78	0.9	5.48
digital	4590	0.27	0.83	-1.57	4.22
manu	4590	0.47	0.12	0.06	2.79
serv	4590	0.41	0.11	0.04	1.5
govern	4590	0.18	0.08	0.04	1.49
pop	4590	5.77	0.92	0.68	7.88

5. Empirical Test

5.1 Benchmark Regression

The average impact of the digital economy on carbon-neutral technological innovation is examined in this work using the two-way fixed model of region effect and time effect, which eliminates the individual unobservable elements of each prefecture-level city that do not change over time. The regression algorithm gradually adds control variables, and Table 2 displays the outcomes. When control variables are added, the digital economy's influence on technological innovation that is carbon neutral is consistently considerably positive at the 1% level. This implies that the degree of technological innovation that is carbon neutral can be greatly increased by the digital economy. After adding all of the control variables to Column (5), the digital economy's influence coefficient on technological innovation that is carbon neutral is 0.754. Through the analysis of the above regression model, it can be said that the digital economy plays a big part in encouraging technology innovation that is carbon neutral, which verifies hypothesis 1.

In terms of the estimated coefficients of the control variables, the influence coefficient of industrialization level on carbon neutral technological innovation is 0.171. This might be because as industrialization levels rise, so does the need for resources and energy. Businesses, academic institutions, and governments are investing more in carbon-neutral technology, encouraging technological innovation, and modernizing their sectors in response to the growing need to protect the environment and advance sustainable development. The service level's influence coefficient on technological innovation that is carbon neutral is 1.436. The service sector keeps encouraging innovation in reducing carbon emissions by launching new models and technologies, which in turn encourages technical innovation that is carbon neutral. Government size has a notably favorable impact on the development of carbon-neutral technologies. This may be because the government clarifies the goals and paths of carbon neutrality by formulating policies and plans related to carbon neutrality, and provides clear guidance for carbon neutral technological innovation. At the 10% level, there is a considerable negative correlation between population density and technological innovation that is carbon neutral. There may not be as much room for renewable energy in crowded urban locations, while traditional fossil energy may still be the main way of energy supply, limiting the widespread application and in-depth development of carbon neutral technologies.

Table 2. Benchmark Regression Results

	(1)	(2)	(3)	(4)	(5)
	gt	gt	gt	gt	gt
digital	0.905***	0.880***	0.775***	0.753***	0.754***
	(87.51)	(74.55)	(58.91)	(54.80)	(54.82)
menu		-0.340***	0.133	0.164**	0.171**
		(-4.36)	(1.64)	(2.03)	(2.11)
serv			1.515***	1.440***	1.436***
			(16.27)	(15.35)	(15.31)
govern				0.615***	0.614***
				(5.50)	(5.50)
pop					-0.0603*
					(-1.83)
_cons	1.436***	1.601***	0.790***	0.704***	1.050***
	(252.97)	(41.76)	(12.70)	(11.01)	(5.27)
Observations	4590	4590	4590	4590	4590
R-squared	0.639	0.641	0.662	0.664	0.664

Note. * P <0. 1, * * P <0. 05, * * * P <0. 01; standard errors are robust and shown in parentheses. These tables are identical to each other.

5.2 Mechanism Test

5.2.1 Scientific and Technological Output

At the 1% significance level, the digital economy's influence coefficient on scientific and technological production is significantly positive, as shown in Column (1) of Table 3. Column (2) adds scientific and technological output based on the original benchmark regression. The coefficient of the digital economy and the coefficient of science and technology output are both positive at 1% level. This demonstrates that the impact is somewhat mediated by the level of scientific and technological production, which supports hypothesis 2. The digital economy can more effectively and rationally allocate resources by using technical tools like artificial intelligence and big data to forecast and assess science and technology spending (Tian et al., 2024). At the same time, digital technology will be used to monitor and evaluate science and technology spending in real-time, identify and correct waste and duplication of investment on time, and reduce unnecessary spending. In addition to offering a strong financial guarantee for technical innovation that is carbon neutral, this will help boost funding for the study of new energy solutions.

5.2.2 Regional Innovation Capability

The digital economy’s influence coefficient on regional innovation capability is significantly favorable at the 1% significance level, as seen in Column (3) of Table 3. Column (4) adds regional innovation capacity based on the original benchmark regression. The regression results show that both the digital economy's coefficient and the regional innovation capacity's coefficient are considerably positive. By showing that regional innovation capacity partially mediates the influence of the digital economy on carbon-neutral technical innovation, it bolsters hypothesis 3. The digital economy efficiently encourages the development and use of green technology and low-carbon solutions by strengthening regional innovation capacity and allocating resources optimally. This will hasten the achievement of carbon neutrality and advance the process of technological innovation in general.

Table 3. Mechanism Test Results

	(1)	(2)	(3)	(4)
	technology	gt	innovation	gt
digital	0.00658***	0.691***	0.584***	0.281***
	(16.27)	(50.81)	(51.51)	(21.58)
manu	0.00251	0.147*	0.226***	-0.0125
	(1.05)	(1.88)	(3.39)	(-0.21)
serv	0.0131***	1.309***	1.106***	0.539***
	(4.76)	(14.52)	(14.31)	(7.55)
govern	-0.0221***	0.829***	1.669***	-0.739***
	(-6.74)	(7.70)	(18.13)	(-8.57)
pop	0.00120	-0.0719**	-0.0694**	-0.00407
	(1.24)	(-2.28)	(-2.56)	(-0.17)
technology		9.720***		
		(19.56)		
innovation				0.811***
				(58.97)
_cons	0.00441	1.007***	2.594***	-1.053***
	(0.75)	(5.27)	(15.80)	(-6.90)
Observations	4590	4590	4590	4590
R-squared	0.113	0.692	0.678	0.814

5.3 Dealing with Endogenous Problems

Cities with higher levels of carbon neutral technical innovation are more likely to establish a digital economy, and better carbon neutral technological innovation may be a cause rather than a result of digital economy expansion. Therefore, this study uses the lag test to exclude endogeneity problem. There might be a delay in the effects of the digital economy on technological innovation that is carbon neutral. To examine the influence of the early digital economy on the current period's carbon-neutral technological innovation, this article regresses the key explanatory variables with lags of one, two, and three periods, respectively. Table 4 presents the findings, which indicate that the digital economy's regression coefficients on technological innovation that is carbon neutral are considerably positive. Although there has been a little variation in the coefficient value from the original, the regression results remain strong.

Table 4. Endogeneity Test

	(1)	(2)	(3)
	gt	gt	gt
L.digital	0.725***		
	(50.91)		
L2. digital		0.709***	
		(48.91)	
L3.digital			0.677***
			(45.17)
manu	0.780***	0.520***	0.179
	(6.88)	(4.58)	(1.55)
serv	2.035***	1.844***	1.688***
	(17.48)	(16.15)	(14.83)
govern	0.424***	0.222*	-0.0883
	(3.72)	(1.94)	(-0.75)
pop	-0.0894***	-0.0712**	-0.0659**
	(-2.81)	(-2.31)	(-2.17)
_cons	0.804***	1.012***	1.338***
	(3.94)	(5.09)	(6.78)
Observations	4320	4050	3780
R-squared	0.658	0.651	0.632

5.4 Heterogeneity Analysis

5.4.1 Heterogeneity Test of Geographical Location

According to the geographical region division of China, this study creates three sub-samples from 270 cities at the prefecture level and higher, then employs group regression using the three sub-samples. From the regression results in Table 5, the digital economy's regression coefficients on technological innovation that is carbon neutral in all three regions are considerably positive at 1% level. Of these, cities in the central and western regions benefit more from the digital economy than do those in the eastern region. This study makes the case that the eastern region's digital economy developed sooner and has a solid basis because of a few factors, including geography, history, and economics. Thus, it's possible that the internet economy's contribution to carbon-neutral technological innovation in eastern cities has peaked, and there isn't much room for expansion (Wu & Zhang, 2024). In contrast, the digital economies in the central and western regions started their development later, so they have greater space for expansion and improvement. As the digital economy continues to grow in popularity and penetration, carbon neutral technological innovation in the central and western areas can be further increased.

Table 5. Heterogeneity Test of Geographical Location

	(1) Eastern region	(2) Central region	(3) Western region
digital	0.613***	0.660***	0.862***
	(35.24)	(19.96)	(29.82)
manu	-0.466***	3.180***	0.923***
	(-5.09)	(9.84)	(4.38)
serv	1.048***	4.783***	1.744***
	(9.05)	(14.19)	(7.58)
govern	0.124	2.505***	1.030***
	(0.91)	(8.01)	(5.04)
pop	0.857***	-0.296***	-0.0686*
	(7.52)	(-3.96)	(-1.72)
_cons	-3.929***	-0.434	0.499*
	(-5.77)	(-0.85)	(1.84)
Observations	1955	1360	1275
R-squared	0.719	0.731	0.639

5.4.2 Heterogeneity Test of Resource Endowments

The primary characteristic of resource-based cities is their richness of natural resources, and resource endowment will have an impact on the digital economy when it comes to technology innovation that is carbon neutral (Wu & Tian, 2024). This study separates the sample cities into resource-based and non-resource-based cities in accordance with the State Council's circular. The regression findings for resource-based and non-resource-based cities are displayed in Table 6's columns (1) and (2), respectively. The findings indicate that, the digital economy's regression coefficients on the two categories of cities' carbon-neutral technological innovation are significantly positive. Among them, compared with non-resource-based cities, the digital economy plays a stronger role in promoting resource-based cities. This paper makes the case that resource-based cities urgently need to adapt as a result of the slow depletion of resources and the growing worldwide awareness of climate change. The digital economy, as a new economic form, can provide resource-based cities with new opportunities and pathways, promote modernization and optimization of their industrial structure, and foster carbon neutral technical innovation.

Table 6. Heterogeneity Test of Resource Endowments

	(1) Resource-based cities	(2) Non-resource-based cities
digital	0.749***	0.706***
	(30.42)	(41.84)
manu	-0.113	1.673***
	(-1.11)	(9.65)
serv	1.043***	3.124***
	(8.56)	(16.72)
govern	0.415**	0.819***
	(2.37)	(5.69)
pop	-0.0340	-0.0830**
	(-0.64)	(-2.02)
_cons	1.080***	-0.126
	(3.63)	(-0.44)
Observations	1836	2754
R-squared	0.612	0.708

5.4.3 Heterogeneity Test of City Level

This paper investigates the regional heterogeneity of the digital economy on carbon neutral technology innovation by dividing 270 sample cities into large cities and medium- small cities based on their size, as per the State Council's Notice on Adjusting the Standards for Dividing City Size. Table 7 shows that, at the 1% level, the digital economy's regression coefficients on carbon-neutral technological innovation are significantly positive for both types of cities. Of them, small and medium-sized cities benefit more from the digital economy than do large ones. This paper argues that through financial innovation and technical integration, the digital economy provides medium-small communities with a range of financing alternatives and promotes the adoption of carbon-neutral technologies.

Table 7. Heterogeneity Test of City Size

	(1)	(2)
	Large cities	Medium-small cities
digital	0.617***	0.800***
	(29.05)	(43.07)
manu	-0.726***	0.864***
	(-6.47)	(7.08)
serv	1.842***	1.673***
	(12.42)	(12.92)
govern	0.483***	0.765***
	(2.76)	(5.24)
pop	-0.0813*	-0.0408
	(-1.72)	(-0.93)
_cons	1.932***	0.260
	(6.30)	(1.01)
Observations	1564	3026
R-squared	0.714	0.652

6. Conclusions and Prospects

The degree of scientific and technical output and the capacity for regional innovation are the two parameters used in this paper to estimate the level of carbon neutral technological innovation in 270 Chinese cities between 2006 and 2022. The effects of the digital economy on urban carbon neutral technology innovation and its internal mechanism are examined in this research using the fixed effect model. The findings indicate that:

(1) Digital economy can significantly promote urban carbon neutral technology innovation. Digital technology can optimize all links of energy production and consumption, run through the whole path of carbon emission reduction, and provide accurate data support for carbon footprint tracking, to regulate and manage carbon emissions more effectively.

(2) According to the effect mechanism, energy infrastructure can foster the development of urban carbon neutral technology innovation by boosting regional innovation capacity and the scientific and technological production.

(3) In various cities, the digital economy has varying effects on the development of carbon-neutral technologies. Carbon neutral technical innovation is greatly aided by the digital economy, which is primarily seen in resource-based cities, medium-small cities, and the central and western cities.

This study proposes the following policy implications based on the analysis above:

First, we need to develop carbon-neutral technology and accelerate the development of the digital economy. To increase market demand for carbon neutral digital technology, the policy support system could be strengthened and businesses involved in carbon neutral technology innovation in the digital economy could receive preferential treatment. However, companies in the digital technology sector are urged to collaborate with those in the conventional energy, industrial, construction, and other sectors to jointly implement projects related to digital transformation and carbon neutral technology innovation. Through digital transformation, the energy efficiency of traditional industries will be improved and carbon emissions will be reduced.

Second, we should focus entirely on how the digital economy affects technical innovation that is carbon neutral, as well as how scientific and technology production and innovation capability play a mediating role. On the one hand, the government increases the financial budget for digital technology research and development, sets up special funds to support digital technology research projects related to carbon neutrality, and guides social capital to participate in digital carbon neutral technology innovation investment. Venture capital and industrial funds will be incentivized to invest in the development of carbon neutral solutions in the digital economy through tax incentives, financial subsidies, and other regulations. On the other hand, we should improve the innovation and entrepreneurship incubation system, build more science and technology business incubators, hackerspaces, etc., and provide all-around support in terms of venue, capital, and technology for start-ups with carbon neutral technological innovation.

Third, we should continuously improve the digital economy's development concepts and modify policies to suit regional circumstances. First, we will support carbon-neutral technology innovation, encourage the deep integration of the digital economy with regionally distinctive industries, and boost investment in the development of digital infrastructure in the central and western regions. Second, the digital economy should be utilized to lessen reliance on conventional resource industries and encourage the diversified growth of resource-based cities. Finally, encourage medium- small cities to participate in the division of the regional industrial chain, integrate into regional innovation networks, and establish channels for interaction with economically developed areas and neighboring large cities.

This study still needs to be improved in a few areas. From the data level, due to the practical obstacles of data acquisition, the data used in this study are up to 2022. We plan to continue to pay attention to and timely supplement the latest data in the follow-up research to further improve the accuracy of the research conclusions. In terms of influence mechanism research, we will try to introduce several intermediaries or moderating variables with important influence, such as industrial structure optimization, to analyze how the digital economy drives carbon neutral technology innovation from more dimensions, and provide theoretical support for relevant policy formulation and practical application.

Ethics approval

Not applicable

Consent for participate

Not applicable

Consent for publication

Not applicable

Conflict for publication

Not applicable

Conflict of interest

The authors declare no competing interests.

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Availability of data and materials

All data can be downloaded from China's National Bureau of Statistics.

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