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Impact of the Development of the Digital Economy on Carbon Emissions --Panel Data Analysis Based on Prefecture-Level Cities in Guangdong Province

Abstract: - With the increasingly severe global climate change problem, low-carbon development has become the consensus of the international community. Based on the panel data of 21 prefecture-level cities in Guangdong Province, China, from 2011 to 2021, this paper analyses in depth the relationship between digital economy and carbon emissions, and explores the impact of digital economy development on carbon emissions and its transmission mechanism. The study finds that: first, the impact of digital economy on carbon emissions is heterogeneous in different regions, with a significant inverted U-shaped relationship between the digital economy and carbon emission levels in the Pearl River Delta (PRD) and the eastern part of Guangdong, while the relationship in the northern part of Guangdong and the western part of Guangdong, which are still in the construction stage of the digital economy, is not significant; second, in the early stage of the development of the digital economy, the maturity of its characteristics will lead to the high inputs and high costs in the process of digital transformation which in turn raises the level of carbon emissions in production and life; third, as the digital economy continues to mature, the early capital, human and technological inputs gradually show a positive net effect, significantly reducing the level of carbon emissions through improved energy use efficiency and optimisation and upgrading of industrial structure. Based on the above findings, the following recommendations are put forward: first, formulate a digital economy emission reduction strategy; second, optimize the construction of digital infrastructure; third, promote the upgrading of industrial structure; fourth, strengthen green technological innovation; fifth, improve the policy incentive mechanism; and sixth, strengthen the coordinated development of the region.

Keywords: Digital Economy, Carbon Reduction, Low Carbon Development , Energy Economy

INTRODUCTION

As the problem of global climate change becomes increasingly serious, low-carbon development has become the consensus of the international community. As the world's largest developing country, China has been actively exploring global climate governance, and in 2022 put forward the dual-carbon goal of "striving to achieve carbon peaking by 2030 and carbon neutrality by 2060", which has been upgraded to a national strategy. Subsequently, the Chinese government released a white paper "China's Green Development in the New Era" in 2023, detailing China's achievements and future vision in promoting green development in the new era, and emphasising the strategic position of green and low-carbon development. In the 2024 government report, emphasis was again placed on strengthening the construction of ecological civilisation and the development of the digital economy, promoting green and low-carbon development, vigorously developing a green and low-carbon economy, and actively and steadily pushing forward carbon peaking and carbon neutrality. Driven by policies at the national level, local governments are also actively exploring specific paths to realise low-carbon development, however better samples have yet to be formed. Guangdong Province, as China's low-carbon pilot province and the frontier of reform and opening-up, has a demonstration effect in its low-carbon development. The Guangdong Provincial Government has introduced a series of policies, such as the "Decision of the CPC Guangdong Provincial Committee on Further Promoting the Ecological Construction of Green and Beautiful Guangdong" and the "Guangdong Province's Peak Carbon Implementation Programme", and implemented the "Peak Carbon Fifteen Actions", reflecting its commitment to low-carbon development and its efforts to promote low-carbon development in Guangdong. ", reflecting its pioneering exploration and practice in green and low-carbon development, aiming to promote the green transformation of the economy and society through a series of concrete measures, build an advanced zone of Beautiful China, and create a green and low-carbon development highland. In this context, the digital economy as a new engine to promote high-quality development[1] and its role in low-carbon development has received widespread attention, and it also provides new solutions for low-carbon development. The digital economy offers new possibilities for improving energy efficiency, optimising energy structure and promoting green technological innovation by facilitating the widespread application of information

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technology and the digital transformation of industries. The development of digital economy effectively reduces the per capita carbon emissions, the incremental carbon emissions and the growth rate of carbon emissions[2,3]. However, the development of the digital economy may also be However, the development of digital economy may also bring new carbon emission problems, such as the energy consumption of data centres and the disposal of e-waste. Therefore, the relationship between digital economy and low carbon development is complex and multidimensional, and in-depth studies are needed to reveal its underlying mechanisms and potential impacts.

The existing literature has extensively explored the factors influencing low-carbon development, including environmental regulation[4] energy mix[5], industrial structure transformation and upgrading[6]. The development of green technologies, and the improvement of innovation level[7] etc. However, research on how the digital economy affects low-carbon development is still in its infancy, and some scholars have empirically found that the development of the digital economy promotes the enhancement of the level of green technological innovation in cities, and reduces the level of urban carbon emissions through the mechanism of green technological innovation[5,7]. The digital economy has made it possible to reduce the level of urban carbon emissions through green technology innovation. Some scholars also believe that the digital economy enables the digital industry to provide networked, digitised and intelligent technological means for the country's green development, which helps industrial upgrading and energy structure optimisation to achieve carbon emission reduction[8]. The digital economy enables the digital industry to provide networked, digital and intelligent technological means for national green development. Some scholars have pointed out that the popularisation of digital technology applications can effectively reduce energy intensity and energy consumption per unit of output, which will lead to a continuous decline in the cost of renewable energy power generation, gradually replace fossil fuel power generation, and reduce resource and energy demand from both the supply and demand sides Reducing Carbon Emissions However, some scholars have pointed out that digital technologies are not the only way to reduce energy demand. However, some scholars have pointed out that while digital technologies are contributing to the low-carbon transformation and green development of the economy and society, the digital economy is gradually becoming one of the major sources of carbon emissions, with a "double-edged sword" effect[9]. Some scholars believe that the digital industrialisation and industrialisation of the industry are not the same as the digital economy. Some scholars believe that there are regional differences in the impact of digital industrialisation and industrial digitisation on carbon emission reduction, and that the carbon emission reduction effect of digital economy is more significant in regions with low digital industrialisation and high industrial digitisation[9]. The impact of the digital economy on carbon emission reduction has regional differences. Some scholars have also pointed out that eastern, non-resource-based and regenerative cities are better able to utilise the digital economy dividend to promote carbon emission reduction[10] . The digital economy is also a key driver of carbon emissions reduction. In addition, some scholars have pointed out that the digital economy has an inverted U-shaped impact on carbon emissions in the city, while the impact on neighbouring cities has a positive U-shaped impact[11]. In conclusion, although studies have mentioned the impact of digital economy on low carbon development, there is still a theoretical gap, especially the lack of empirical studies at the regional level. There is an urgent need for studies that are tailored to the Chinese scenario, locally focused and with demonstration effects. As a major digital economy province, Guangdong Province is representative and important in the study of the relationship between digital economy and low carbon development. The digital economy can significantly contribute to carbon emission reduction in Guangdong Province and there is heterogeneity, with significant differences between the Pearl River Delta (PRD) region and non-PRD regions[12]. The digital economy can significantly contribute to carbon emission reduction in Guangdong and there is heterogeneity . However, there are fewer specific studies around Guangdong Province.

Guangdong Province, as a strong engine of China's economic development, has reached a per capita GDP of US$12,800 in 2020, with an urbanisation rate of 71.7% and a tertiary sector share of 56.5%, which reflect the continued optimisation of the economic structure and the significant acceleration of the urbanisation process in Guangdong Province, and have played an important role in driving the country's progress. However, after analysing the carbon emission data of 21 prefectural-level cities in Guangdong Province from 2011 to 2019, this paper finds that although Guangdong Province has basically reversed the rapid growth of CO_2 in recent years, presenting a situation of "preliminary basic conditions for carbon peaking, but the space for carbon reduction is still relatively large", it is still faced with the serious challenge of carbon emission management, which is mainly manifested in the following aspects. In terms of spatial distribution of carbon emissions, urban carbon emissions in Guangdong Province show obvious clustering characteristics, but this characteristic is gradually weakening, indicating that the spatial differences in carbon emissions in Guangdong Province are widening; in terms of energy consumption, the Pearl River Delta (PRD) cities, such as Guangzhou, Shenzhen, and Foshan, have long been hotspots of high carbon emissions due to their large populations and dominant industrial sectors[13]. With urbanisation and modernisation, energy demand has surged, further pushing up carbon emissions. in 2020, the combined energy consumption of the above-scale industries in Guangdong province has exceeded the level of the same period last year[14] In 2020, the combined energy consumption of Guangdong's above-scale industries has already exceeded the level of the same period last year, and the combined energy consumption of the six major energy-consuming industries has increased by 3.6%. Guangdong's energy production capacity has increased significantly since the 13th Five-Year Plan; in terms of energy structure, the formation of a diversified energy consumption pattern is accelerating, and the installed capacity of new energy power generation is expected to reach 102.5 million kilowatts by 2025. The power structure is continuously optimised. And Guangdong Province, as one of the national carbon emissions trading pilots, the total annual emission quotas in its carbon market amount to about 400 million tonnes, ranking first in the country and third in the world in terms of the size of the quotas, which shows the huge carbon reduction potential of the carbon financial market[15]The carbon financial market has a huge potential for carbon reduction. In the future, Guangdong Province still needs to continue to explore in economic development, energy structure optimisation, low carbon pilot work and carbon financial market, in order to achieve carbon peak and low carbon development goals, and embark on the road of green and high-quality development[13-17].

In summary, this study focuses on the empirical research at the level of prefecture-level cities in Guangdong Province, using the panel data of 21 prefecture-level cities in Guangdong Province from 2011 to 2021, constructing a dataset with the help of big data analysis methodology, establishing an ordinary panel benchmark regression model, selecting carbon dioxide emissions and digital economy index as variables for empirical analysis, in-depth analysis of the relationship between the digital economy and carbon emissions, and exploring the impact of digital economy development on carbon emissions and its transmission mechanism, and ultimately drawing conclusions. We will analyse the relationship between digital economy and carbon emission, explore the impact of digital economy development on carbon emission and its transmission mechanism, and finally draw conclusions and provide new theoretical support and development suggestions for the promotion of "Green and Beautiful Guangdong", high-quality development, and the achievement of the "dual-carbon" goal. This will provide a scientific basis and policy recommendations for the low-carbon development strategy of Guangdong Province and the whole country. Carbon Emission Trends in 22 Prefecture-level Cities in Guangdong Province can be seen in Figure 1.

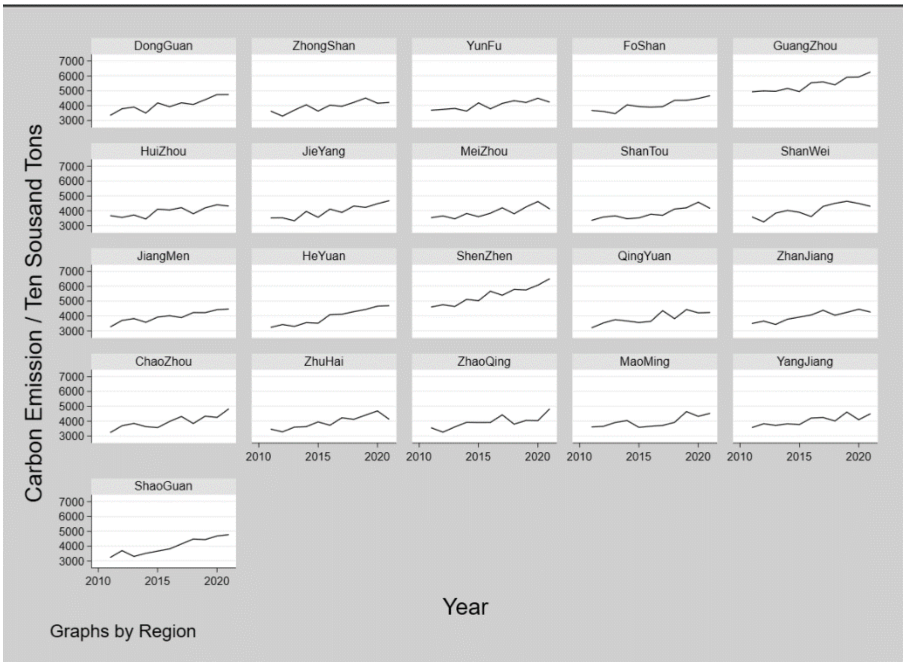

Figure 1 Carbon Emission Trends in 22 Prefecture-level Cities in Guangdong Province, 2011-2021

I. Data, variables and methods

A. Data sources

Considering the availability and completeness of the data, this paper selects 21 prefecture-level cities under the jurisdiction of Guangdong Province in China as the research object, with the time span from 2011 to 2021, and the data of the indicators selected in the paper are mainly from the 2012-2022 China Urban Statistical Yearbook, statistical yearbooks of each prefecture-level city, etc., except for some indicators such as the Digital Financial Inclusion Index, and the missing values are filled in by linear interpolation method and linear trend patching for the approaching years. The descriptive statistics of the variables used are shown in Table 1.

Table 1 Descriptive statistics of variables

variant	observed value	average value	(statistics) standard deviation	minimum value	maximum values
Logarithmic conversion of carbon emissions	231	8.310	0.135	8.070	8.780
Digital Economy Squared	231	1.575	2.552	0.00111	14.74
Digital Economy Index	231	1.033	0.714	-0.0334	3.839
Logarithm of population size	231	5.964	0.503	4.660	6.920
environmental pollution	231	0.0528	0.0355	0.00498	0.218
energy consumption	231	1.978	0.0956	1.737	2.405
government support	231	0.135	0.0442	0.0557	0.291

B. Model selection:

Based on the above theoretical analysis, this paper establishes a panel regression model to empirically analyse the impact of digital economic development on carbon emissions. Considering the large fluctuation of data with different measures, this paper takes logarithmic treatment for some variables, and the following is the benchmark regression model:

$$LNCE_{it} = \beta_0 + \beta_1 SDige + \beta_2 Dige + \sum_i \alpha_i \times Contorl + \mu_{it} + \sigma_{it} + \varepsilon_{it}$$

where LNCEit denotes the explanatory variable, i.e., the CO2 emissions of the ith city in year t. Dige and SDige denote the core explanatory variables, which are the digital economy index and its squared term, respectively; Controls is a series of control variables, mainly including population size, environmental pollution, energy consumption, and governmental support; μit, σit, and εit are the individual and time effects, respectively and the random disturbance term.

C. Variable Selection

Explained variable: CO2 emissions. Currently, there are two main types of measurement methods for CO2, the sectoral accounting method and the apparent emission accounting method. This paper draws on[18] 's approach to calculate top-down data on CO2 emissions from fossil fuel combustion (crude coal, crude oil, and natural gas) using relatively readily available energy supply statistics by multiplying the apparent consumption of the fuel by the corresponding carbon conversion factor and subtracting the use-and-loss component of the apparent consumption of non-energy fuels.

Core explanatory variable: digital economy index. This study aims to assess the overall level of development of the digital economy, focussing on Internet penetration and digital finance penetration. At the city level, we adopt the[19] proposed multidimensional assessment framework, which integrates key indicators such as Internet access rate, proportion of employees, industry output, and mobile coverage. Specifically, we analysed the number of Internet broadband users per 100 people, the proportion of employees in the computer and software industry in the total number of employees in towns and cities, the amount of telecommunication services per capita, and the number of mobile phone users per 100 people. These data are all sourced from the China Urban Statistical Yearbook. In the field of digital finance, we refer to the China Digital Inclusive Finance Index jointly published by the Digital Finance Research Centre of Peking University and Ant Gold Service Group[20], which provides a comprehensive and in-depth perspective for assessing the development of digital finance. In order to integrate these indicators and form a unified measure, we apply principal component analysis to normalise and downscale the data, resulting in a comprehensive digital economy development index, referred to as the Dige.This index aims to provide a quantitative perspective to assess and compare the progress and achievements of different cities in the digital economy. Through this approach, we are able to more accurately grasp the dynamics of the digital economy and provide a scientific basis for policy formulation and resource allocation.

Control variables: considering the large number of factors affecting CO2 emissions, this paper draws on existing research results[21] , introducing relevant variables to control the accuracy of the results of the impact of the digital economy on carbon emissions, population size (popu), environmental pollution (poll), energy consumption (pener), government support (gover). Population size is measured by the total urban population, and existing studies have shown that the contribution of the household sector to carbon dioxide emissions should not be underestimated, and that population size is an important aspect that reflects the increase in carbon emissions through energy consumption at the household level. Existing studies have generally used industrial wastewater emissions, industrial sulphur dioxide emissions and industrial solid waste emissions to measure the environmental pollution status of a region, but due to the lack of data on solid waste emissions at the prefectural level, industrial wastewater emissions, industrial sulphur dioxide emissions and industrial fume (dust) emissions of each city are selected, drawing on[22] practice, the environmental pollution index was calculated. China is a large coal-consuming country and one of the main sources of carbon emissions, coal occupies a major position in the energy consumption structure, and thermal power generation is one of the main ways to consume coal, and the per capita electricity consumption of prefecture-level cities was selected to measure energy consumption.

II. Empirical analysis

A. *Baseline regression analysis*

In order to investigate whether the digital economy affects carbon emissions in a non-linear relationship, so this study adds the digital economy quadratic term to the model, and the regression results are shown in column (2) of Table 2. In order to ensure that the added control variables are not redundant and achieve the best modelling effect, this study adopts the stepwise regression method for analysis. As shown in the table, the coefficient of the digital economy square (i.e., the quadratic term of the digital economy level) after the addition of so control variables is -0.5985, which is significant at the 5% level, showing a significant negative correlation; while the coefficient of the digital economy level is 0.8540 and is significant at the 5% level, showing a significant positive correlation, which shows that there is an inverted U-shape relationship between the level of the digital economy and the carbon emissions, which is consistent with the This is consistent with the research findings of Mu Jun et al. 's research conclusion is consistent. That is, in the initial development period of the digital economy, its immature characteristics lead to the need for higher inputs and costs in the process of digital transformation. At this stage, the development of the digital economy not only pushes the increase of carbon emissions as it requires a large amount of energy consumption and resource inputs, but also prompts companies to invest more resources in the research and development of green technologies in order to meet environmental requirements. This dual pressure has led to a sustained upward trend in carbon emissions in the early stages of the digital economy. However, as the digital economy continues to evolve and mature, the early capital, human and technological investments begin to show positive cumulative effects. During this period, the use of energy became more efficient, the industrial structure underwent optimisation and upgrading, and the production costs of enterprises were effectively controlled, while the efficiency of technological research and development was significantly improved. Together, these changes have led to a decline in carbon emissions, reflecting the positive impact of the digital economy on the environment at the maturity stage.

Table 2 Benchmark regression results

variant	(1)	(2)	(3)	(4)	(5)
Digital Economy Squared	-0.0127*** (0.0048)	-0.0130*** (0.0049)	-0.0135** (0.0053)	-0.0137** (0.0056)	-0.0130** (0.0061)
Digital Economy Index	0.204*** (0.0196)	0.204*** (0.0197)	0.207*** (0.0215)	0.207*** (0.0225)	0.204*** (0.0248)
Logarithm of population size		0.0041 (0.0064)	0.0038 (0.007)	0.0075 (0.0073)	0.0077 (0.0073)
environmental pollution			-0.08 (0.103)	-0.128 (0.115)	-0.100 (0.138)
energy consumption				0.0740 (0.0489)	0.0783 (0.0481)
government support					0.0533 (0.0917)
a constant (math.)	8.120*** (0.0135)	8.095*** (0.0435)	8.099*** (0.0469)	7.934*** (0.130)	7.917*** (0.130)
observed value	231	231	231	231	231
No. of groups	21	21	21	21	21

Note: 1. "*", "**", "***" denote significance at 10%, 5% and 1% significance levels, respectively; 2. Robust standard errors are in parentheses. Same as below.

B. Robustness Tests

To further test the non-linear impact of the digital economy on carbon emissions, this paper conducts a robustness test by replacing the measure of the explanatory variable (carbon emissions) and treating the explanatory variable one period lagged.

Replacing explanatory variables. Drawing on[23], the model (1) of Table 3 shows the impact of digital economy on per capita carbon emissions., the explanatory variables are replaced by per capita carbon emissions to further observe whether the conclusions are still valid after replacing the variables. Model (1) in Table 3 shows the regression results of the impact of the digital economy on per capita carbon emissions, which is basically in line with the conclusions of the previous section, proving the robustness of the results.

Lagged explanatory variables. This paper further ensures the robustness of the study by means of lagged explanatory variables, and the results are shown in model (2) of Table 3, which shows that the inverted U-shaped relationship of the digital economy on carbon emissions in the lagged period all holds.

Table 3 Robustness regression results

variant	Modelling (1)	Models (2)
Digital Economy Squared	-0.195*** (0.0611)	-0.0169*** (0.0058)
Digital Economy Index	2.175*** (0.319)	0.218*** (0.0219)
Logarithm of population size	-10.74*** (1.095)	0.0031 (0.0085)
environmental pollution	-2.694 (2.660)	-0.209* (0.123)
energy consumption	0.251 (0.825)	0.0570 (0.0794)
government support	2.312 (3.026)	-0.0891 (0.0654)
a constant (math.)	73.31*** (7.539)	8.025*** (0.169)
observed value	231	210
R^2	0.4249	0.5293
No. of groups	21	21

C. Heterogeneity test

Due to the extensive geographical location of Guangdong Province, there are obvious differences in the level and development of digital economy among the eastern Guangdong, northern Guangdong, Pearl River Delta (PRD) and western Guangdong, with the PRD region having better economic development. In this paper, inter-group heterogeneity test was conducted according to regional geographical locations to explore the differences in the impact of digital economy on carbon emissions in eastern Guangdong, northern Guangdong, Pearl River Delta and western Guangdong, and the detailed regression results are shown in Table 4.

Table 4 Heterogeneity test results

	(1) Pearl River Delta	(2) Eastern Guangdong	(3) western Guangdong	(4) northern Guangdong
Digital Economy Squared	-0.0139**	0.0599*	-0.0044	0.0052
	(0.0057)	(0.0348)	(0.0755)	(0.0415)
Digital Economy Index	0.193***	0.0549	0.0849	0.139***
	(0.0232)	(0.0731)	(0.205)	(0.0512)
Logarithm of population size	0.0343**	0.0242	-0.0472	0.0429
	(0.0151)	(0.0293)	(0.0338)	(0.03)
environmental pollution	-0.0801	0.630	2.176***	-0.382***
	(0.133)	(0.446)	(0.505)	(0.127)
energy consumption	0.0882	0.188	-0.406***	0.539***
	(0.0802)	(0.134)	(0.131)	(0.124)
government support	0.658***	0.872***	2.127	-0.411**
	(0.234)	(0.292)	(1.629)	(0.188)
a constant (math.)	7.693***	7.529***	8.961***	6.948***
	(0.203)	(0.424)	(0.547)	(0.379)
observed value	99	44	33	55
No. of groups	9	4	3	5

As shown in the data in the table, there is a significant inverted U-shaped relationship between the digital economy and carbon emission levels in the PRD and eastern Guangdong, but the significance of the inverted U-shaped relationship does not pass in northern and western Guangdong. This is due to the fact that the development of the digital economy is lagging behind and the digital economy is still in the pre-medium construction stage in the northern and western regions, and the reduction of carbon emissions facilitated by the completion of the construction of the digital economy infrastructure, etc. cannot be realised in the northern and western regions of Guangdong, which may be related to the level of economic development of these regions, the industrial structure and energy consumption pattern, and environmental protection policies. The reduction of carbon emissions promoted by the completion of the construction of digital economy infrastructure, etc. cannot be realised in Northern and Western Guangdong, which may be related to the level of economic development, industrial structure, energy consumption pattern and environmental protection policies of these regions. Compared with the PRD region, Northern and Western Guangdong have a lower level of economic development, and their industrial structure may be more in favour of traditional manufacturing and agriculture, which may have a relatively higher carbon emission intensity, while the penetration and application of the digital economy may not be extensive enough, and hence its impact on carbon emissions may not be as significant as that of the PRD region. In addition, the energy consumption structure in northern and western Guangdong may be more reliant on traditional energy sources, such as coal and oil, while the role of the digital economy in promoting energy efficiency and the use of cleaner energy may not have been fully utilised. There may also be differences in the implementation and effectiveness of environmental protection policies in these regions, which may have affected the performance of the relationship between digital economy development and carbon emissions.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusion

In the study exploring the relationship between the digital economy and carbon emissions, this study takes prefecture-level cities in Guangdong Province as a sample, and analyses in-depth the impact of the digital economy on carbon emissions and its transmission mechanism based on panel data from 2011 to 2021. It is found that in the initial development stage of the digital economy, its immature nature leads to high inputs and costs in the process of digital transformation, which in turn raises the level of carbon emissions in production and life. However, as the digital economy continues to mature, the early capital, human and technological inputs gradually show a positive net effect, with improved energy use efficiency, optimised and upgraded industrial structure, lower production costs for enterprises, and improved efficiency of technological research and development, which significantly reduces the level of carbon emissions.

B. Policy recommendations

The findings of this study have important implications for the low-carbon development strategy of Guangdong Province and the whole country. Especially in the context of green and beautiful Guangdong, digital economy is not only a new engine to promote high-quality economic development, but also a key path to realise green and low-carbon transformation. The development of digital economy has strengthened the elemental foundation, expanded the infinite space, and provided the fundamental guarantee for green development. In order to better promote the construction of green and beautiful Guangdong, this study puts forward the following recommendations:

1. Formulate a digital economy emission reduction strategy: The high energy consumption characteristics of the digital economy determine that the development of the digital economy must be synergistically promoted with greening, and the formulation of a good digital economy emission reduction strategy is conducive to the coordinated promotion of the digital economy and low-carbon development. As the impact of digital economy on carbon emissions is heterogeneous in different regions, city clusters and non-city cluster areas, and in Guangdong Province, the level of digital economy development and the regional development situation vary greatly, differentiated and dynamic digital economy emission reduction strategies should be formulated according to local conditions. Regions in western Guangdong and northern Guangdong with a lower level of digital economy development should establish simultaneous digital industries with their own development characteristics to guide their flow to low-pollution and low-emission industries according to their own resource endowments and economic development advantages. As for the regions with a higher level of digital economy development represented by eastern Guangdong and the Pearl River Delta region, they should continue to optimise their industrial structure, improve the efficiency of energy use and stimulate the carbon emission reduction effect of the digital economy.

2. Optimising the construction of digital infrastructure: As the digital economy is based on digital platforms to generate extensive scale effects and economies of scope, it is necessary to increase the construction of new types of infrastructure that host digital technologies and platforms. Increase investment in digital infrastructure, especially in regions where the development of the digital economy is relatively lagging behind, such as northern Guangdong and western Guangdong, to accelerate energy conservation and emission reduction in digital infrastructure through the construction of digital infrastructure, promote the green and low-carbon development of the digital economy, and facilitate the widespread application of information technology and the digital transformation of industries.

3. Promoting industrial structure upgrading: The digital economy can not only directly curb carbon emissions, but also indirectly have a significant curbing effect on carbon emissions by promoting industrial structure upgrading. Regions with strong digital economy development have a much greater impact on carbon emission intensity and efficiency than those with weak digital economy development. Encourage and support traditional industries to improve energy efficiency through digital transformation, digitally empower the green transformation of enterprises, and reduce carbon emissions, and at the same time cultivate and develop low-carbon and environmentally friendly emerging industries, so as to promote the upgrading of the industrial structure in the direction of greener and more efficient.

4. Strengthening green technological innovation: technological innovation is an important way for the digital economy to promote carbon productivity, and original innovation mainly comes from enterprises. Increase support for green technology research and development, encourage enterprises to carry out green innovation, and reduce energy consumption and carbon emissions in the production process through technological innovation, so as to achieve a win-win situation for both economic development and environmental protection.

5. Improving policy incentives: Governments should continue to promote digital economy development strategies, strengthen policy guidance and support for digital economy development, optimize the top-level design of relevant systems, adopt dynamic and differentiated development strategies to empower the green development of the economy, and achieve the co-development of digitalisation and decarbonisation. Formulate and improve relevant policies to provide a favourable policy environment for the development of the digital economy, including tax incentives, financial subsidies, green credit, etc., and incentivise enterprises to adopt clean energy and environmentally friendly technologies. In addition, expand the breadth and depth of the integration of digital factors with other factors of production, promote the marketisation of energy-saving and emission reduction policy tools, and formulate differentiated and dynamic policy measures. Improve the policy incentive mechanism to empower the development of the digital economy and promote low-carbon development.

6. Strengthening regional coordinated development: Considering the differences in the development of the digital economy in different regions of Guangdong Province, differentiated low-carbon development strategies should be implemented to promote coordinated development among regions. In addition, the development of digital economy has a significant spatial spillover effect, which can affect the carbon emission level of neighbouring regions. Considering the spatial heterogeneity, the digital economy of the cities in the eastern region has a significant emission reduction effect on the carbon emission of the region, and the spatial spillover effect of the digital economy development on the districts adjacent to the cities is also significant, so we can drive the development of the digital economy of other surrounding areas with the eastern part of Guangdong and the Pearl River Delta to achieve the goal of a green and beautiful Guangdong.

DATA SHARING AGREEMENT

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

DECLARATION OF CONFLICTING INTERESTS

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REFERENCES

[1] Guo, Y., & Jiang, F. (2023). How Does the Digital Economy Drive High-Quality Regional Development? New Evidence From China. Evaluation Review, 193841X231213128.

[2] Hu, Y. (2023). Has the Development of The Digital Economy Reduced the Growth Rate of Carbon Emissions? Frontiers in Business, Economics and Management.

[3] Liao, Z., Ru, S., & Cheng, Y. (2023). A Simulation Study on the Impact of the Digital Economy on CO2 Emission Based on the System Dynamics Model. sustainability.

[4] Li, Z., & Liu, Z. (2023). Does environmental regulation affect urban green technology innovation in China? Evidence from the low-carbon city pilot policy. Frontiers in Energy,. 11.

[5] Yu, D., Silin, L., & Tengjun, Z. (2021). Industrial Structure Effect of China's Urban Air Quality Improvement: a Natural Experiment of COVID-19. Journal of Finance and Economics Journal of Finance and Economics , 47, 19-34.

[6] Zhang, Y., He, S., Pang, M., & Li, Q. (2023). Green Technology Innovation of Energy Internet Enterprises: Study on Influencing Factors under Dual Carbon Goals. energies.

[7] Chen, X. L., & Zheng, X. G. (2022). Research on the influence of digital finance on urban green technology innovation. 2022 3rd International Conference on Education, Knowledge and Information Management (ICEKIM), 785-788.

[8] Lyu, K., Yang, S., Zheng, K., & Zhang, Y. (2023). How Does the Digital Economy Affect Carbon Emission Efficiency? Evidence from Energy Consumption and Industrial Value Chain.

[9] Wang, L., Chen, Y., Ramsey, T., & Hewings, G. (2021). Will researching digital technology really empower green development? Technology in Society.

[10] Yang, T., & Wang, R. (2023). Research on the Impact of Green Finance and the Digital Economy on the Energy Consumption Structure in the Context of Carbon Neutrality. sustainability.

[11] Lv, J. (2023). Digital Economy and Urban Carbon Emissions in China: An Empirical Study Based on The Spatial Dubin Model. Management.

[12] Ma, Y., Wang, S., & Zhou, C. (2023). Can the Development of the Digital Economy Reduce Urban Carbon Emissions? Case Study of Guangdong Province. land.

[13] Wang, J., & Liu, A. (2022). Scenario Analysis of Energy-Related CO2 Emissions from Current Policies: A Case Study of Guangdong Province. sustainability.

[14] Ren, F., & Long, D. (2021). Carbon emission forecasting and scenario analysis in Guangdong Province based on optimised Fast Learning Network. Journal of Cleaner Production.

[15] Cheng, B., Dai, H., Wang, P., Xie, Y., Chen, L., Zhao, D., & Masui, T. (2016). Impacts of low-carbon power policy on carbon mitigation in Guangdong Province, China. energy Policy, 88, 515-527.

[16] Feng, J., Zeng, X., Yu, Z., Tang, S., Li, W.-C., & Xu, W. (2019). Status and Driving Forces of CO2 Emission of the National Low Carbon Pilot: Case Study of Guangdong Province during 1995-2015. energy Procedia.

[17] Wang, P., & Zhu, B. (2016). Estimating the Contribution of Industry Structure Adjustment to the Carbon Intensity Target: A Case of Guangdong. sustainability, 8, 1- 11.

[18] Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., Mi, Z., Liu, Z., & Zhang, Q. (2018). China CO2 emission accounts 1997-2015. Scientific Data, 5(1), 170201.

[19] Huang, Qunhui, Yongze Yu, & Songlin Zhang. (2019). Internet development and manufacturing productivity improvement: internal mechanism and Chinese experience. China Industrial Economics, 8, 5-23.

[20] Guo, F., Wang, J.I., Wang, F., Kong, T., Zhang, X., & Cheng, C.Y.. (2020). Measuring the development of digital inclusive finance in China: indexing and spatial characterisation. Economics (Quarterly), 19(4), 1401-1418.

[21] Tian, J. & Wang, Y. H.. (2018). Analysis of spatial spillover effects of fiscal decentralisation, local government competition and carbon emissions. China Population-Resources and Environment, 28(10), 36-44.

[22] Dong, Zhiqing & Wang, Hui. (2019). The "local-neighbourhood" green technology progress effect of environmental regulation. China Industrial Economics, 1, 100-118.

[23] Shao, Shuai, Ke Zhang, & Jianmin . (2019). Energy saving and emission reduction effects of economic agglomeration: theory and Chinese experience. Management World, 35(1), 36-60, 226.