frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 27 January 2025
DOI 10.3389/fenvs.2025.1470724

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OPEN ACCESS

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RECEIVED 26 July 2024
ACCEPTED 02 January 2025
PUBLISHED 27 January 2025

CITATION
Yi J (2025) Digital government and carbon emissions: evidence from China.
Front. Environ. Sci. 13:1470724.
doi: 10.3389/fenvs.2025.1470724

Digital government and carbon emissions: evidence from China

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With the continuous modernization of national governance, the role of digital government construction in environmental protection and sustainable development has become increasingly prominent. This study explores the intrinsic link between digital government construction and carbon emissions and the mechanism of its influence based on 30 provincial-level panel data in China from 2017 to 2021. The study finds that digital government construction can significantly suppress carbon emissions, and this conclusion still holds after considering endogeneity issues and after multiple robustness tests. The study further reveals that digital government can inhibit carbon emissions through the internal mechanism of promoting industrial structure upgrading and green technology innovation. In addition, the inhibiting effect of digital government on carbon emissions is more pronounced in eastern and central provinces, provinces with higher levels of government transparency, higher levels of digital government development, and higher intensity of environmental regulation. This study provides an important reference for understanding the role of digital government construction in promoting green development and achieving carbon emission reduction targets.

KEYWORDS

Digital government, carbon emission, industrial structure upgrading, green technology innovation, heterogeneity

1 Introduction

Greenhouse gases generated by carbon emissions contribute to global climate change, indirectly triggering health problems, such as heat waves, extreme weather events, declining air quality, and increased spread of infectious diseases. As the world's largest carbon emitter, China is duty-bound to combat climate change and achieve sustainable development. In 2022, the Chinese government announced the Implementation Plan for Pollution Reduction, Carbon Reduction, and Synergistic Efficiency, explicitly promoting synergistic emission reduction of air pollutants and CO_2. The State Council issued the Guiding Opinions on Strengthening the Construction of Digital Government. The Opinions point out to promote green and low-carbon transformation, accelerate the construction of an intelligent monitoring and dynamic accounting system for carbon emissions, and promote the formation of a new pattern of green and low-carbon development that is intensive, economical, circular, efficient, and inclusive and shared, and serve to guarantee the smooth realization of the goals of carbon peaking and carbon neutrality. Digital government, as an essential means to enhance governance capacity and public service, is rapidly gaining popularity at all levels of government. Through advanced technologies such as big data, the Internet of Things, and blockchain, digital government has optimized public services and management efficiency and provided new ideas and tools for environmental governance and carbon emissions management (Zhu et al., 2024).

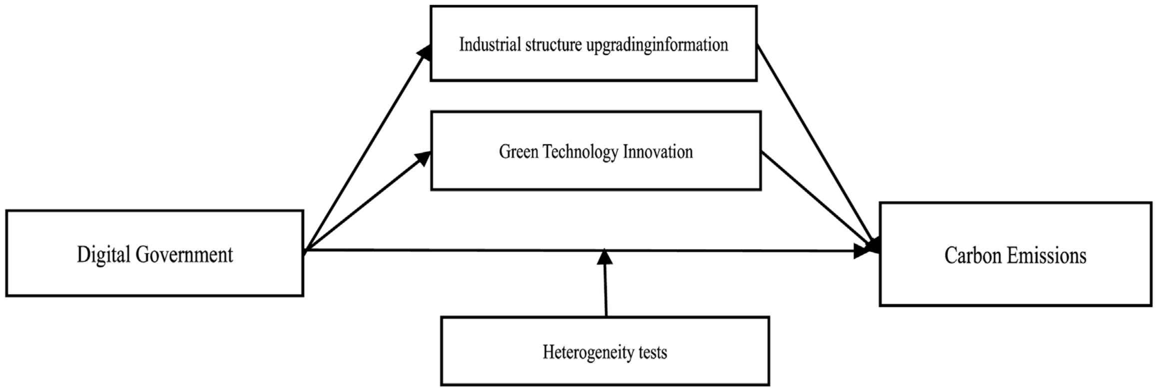

FIGURE 1
Theoretical model.

As the construction of digital governments is carried out in various countries, the ways of building digital governments and their effectiveness have received extensive attention from society and academia. According to the different objects served by digital government, the United Nations usually classifies the practices related to digital government into three categories: G2B (Government to Business), G2G (Government to Government), and G2C (Government to Citizens). From the government-to-business perspective, Hu et al. (2024) found that digital government construction can improve business performance by improving business operations and business management capabilities through data openness (Hu et al., 2024). Yue and Hong showed that digital government positively affects the quality of enterprise development, and digital government has a more significant effect on the quality of high-tech enterprise development than non-high-tech enterprises (Yue and Hong, 2023). From the government-government perspective, Bi and Xu found that the digital government increases the number of government approval services, reduces the institutional transaction costs of enterprises dealing with the government, and improves the efficiency of the government through the introduction of the one-government machine (Bi and Xu, 2024). Zhao et al. found that in unexpected public crises, people access public services through digital government-related applications, which promotes government trust (Zhao et al., 2020). From a government-citizen perspective, the study focuses on the impact of digital government on residents' perception of a better life and social equity (Zheng et al., 2023; Ma, 2024). Digital government construction has played an important role in political, economic, and social fields. However, the research on the impact of digital government construction on the ecological environment is still insufficient and needs to be further enriched and improved.

Since introducing the "dual-carbon" strategy, China has made remarkable achievements in reducing carbon emissions. In the field of carbon emission research, most studies in the past focused on the enterprise level, exploring the impact of enterprise activities on the total amount of carbon emissions or analyzing the interaction between the carbon trading mechanism and carbon emissions from the market perspective (Li and Li, 2022; Wu et al., 2021), as well as examining the role of the manufacturing industry in carbon emission reduction from the industry perspective (Zhang and Cheng, 2021). Achieving carbon peak and neutrality has become an important assessment goal for the government. In order to understand China's peak carbon and carbon neutrality issues more comprehensively, it is necessary to expand the research perspective to the government level and analyze in depth how the government influences carbon emissions through its policies and actions. The government's influence on carbon emissions can be seen in two key areas: first, the formulation and implementation of macro policies, such as the national "low-carbon city pilot policy." The second is local governments' behavior and governance, a dimension often overlooked in existing research. However, local governments are crucial in implementing national macro-policies and promoting low-carbon development.

Huang and others pointed out that the construction of a digital government is to lay the foundation for the modernization of the national governance system and governance capacity through the extensive application of a new generation of digital technologies, such as the Internet, big data, artificial intelligence, and other digital technologies, in combination with organizational change, in order to improve the transparency, management efficiency, service quality and responsiveness of the government (Huang et al., 2022). From the perspective of government functions, digital government realizes the excess and transformation from management-oriented government to service-oriented government. Compared with the traditional government, the digital government, through the deep integration of information technology and efficient empowerment of data, has achieved a significant improvement in business processing efficiency, greater openness and transparency of information, and the convenient construction of digital platforms, promoting the government to a higher level of intelligent development (Song and Jia, 2023). Li and Lu (2024) found that digital government can facilitate enterprises to reduce pollutant and carbon emissions. Zhang found that carbon emissions and government support are closely related, and the attention of local governments can significantly inhibit carbon emissions (Zhang, 2024). Meng et al. (2024) found that government digital governance can boost urban carbon emission reduction. What impact will these new features exhibited by the digital government have on carbon emissions? Can they contribute to the further advancement of the "dual-carbon" strategy? Can digital government significantly curb carbon

TABLE 1 Summary of digital government evaluation indicator system.

First-level indicators	Second-level indicators	Measurement methods	Data sources	Weight w
Technological factor	Digital Technology Infrastructure	Internet broadband ports *per capita*	China Statistical Yearbook	0.0610
	Investment in fixed assets in digital technology	Investment in all social fixed assets in the information transmission, software and information technology services industry	China Statistical Yearbook	0.2434
	Digital Technology Human capital	Employment in urban units of the information transmission, software and information technology services sector	China Statistical Yearbook	0.0219
Organizational factors	Provincial Government Allocation of attention	Digital governance structure set up and level in each province. The code for organizations directly under the provincial government is 3, the code for departmental management organizations managed by the provincial government office is 2, the code for organizations within the departments such as the Economic and Information Office and the Department of Industry and Information Technology is 1, and the code for the absence of a relevant digital governance structure is 0	Summary of Government Websites and Related Scholarly Research (Huang and Sun, 2018)	0.1597
	Central Government Degree of importance	Number of digital government-related policies, with 1 policy counted as 1, cumulatively added up	Government website, BYU Fabulous	0.2738
	Government finances Resource capacity	General budget income *per capita*	China Statistical Yearbook	0.1298
Environmental factor	Public External demand pressure	Number of mobile Internet users *per capita* by province	China Statistical Yearbook	0.0561
	External to the company Demand pressure	Number of industrial enterprises above designated size	China Statistical Yearbook	0.0292
	Pressure of inter-governmental competition	Average of the performance level of digital government websites in neighboring provinces, expressed in terms of the pass rate of government website spot-checks	Government website	0.0251

emissions? If so, what are the specific mechanisms through which digital government can contribute to carbon reduction? What are the differences in the effectiveness of digital government in controlling carbon emissions in different regions of China? What are the successes of digital government in managing carbon emissions in China, and can they be replicated in other countries?

Based on this, this article tries to answer the above questions. The article adopts China's 30 provincial panel data from 2017–2021. It empirically tests them using a two-way fixed effects model to explore the specific impact and mechanism of action between digital government and carbon emissions. The study not only enriches the theory of environmental governance and promotes the cross-fertilization of digital governance and environmental science but also provides guiding policy recommendations and implementation paths for Chinese governments at all levels in promoting the construction of digital government and the management of carbon emissions, which will help China to achieve the goal of carbon neutrality and promote the global emission reduction.

The innovations of this study are summarized as follows: (1) Innovation in research perspective: by combining two fields, political science and environmental science, the study demonstrates the innovation of interdisciplinary research perspective. This integration not only provides a new research dimension for the two disciplines, but also helps to reveal the unique impact of digital government building in terms of carbon emissions, which is relatively rare in previous studies. (2) Innovation of research content: this study is innovative in exploring the mechanism of the impact of digital government construction on carbon emissions. Through in-depth analysis of the mediating role of industrial structure upgrading and green technology innovation, this study reveals the specific paths through which digital government construction affects carbon emissions, which may not have been fully explored in previous studies. (3) Innovation of entry point: This study explores the heterogeneity of the impact of digital government construction on carbon emissions in terms of geography, government transparency, level of digital government construction, and intensity of environmental regulation. This study provides an important empirical basis and theoretical reference for the development of precise carbon emission reduction policies, which has not yet received sufficient attention in previous academic research.

2 Theoretical mechanisms and research hypotheses

2.1 The direct effect of digital government on carbon emissions

In promoting the digital transformation of eco-environmental protection, the digital government relies on policy and institutional

TABLE 2 Descriptive statistics of relevant variables.

Variable	Obs	Mean	Std.Dev.	Min	Max
C	150	1.810	1.776	0.196	10.556
Dig	150	0.324	0.162	0.064	0.663
Ind	150	1.491	0.747	0.852	5.297
Tec	150	8.372	1.161	5.288	10.874
Gdp	150	11.071	0.394	10.258	12.123
Cit	150	0.634	0.103	0.463	0.893
Pop	150	7.804	0.459	6.726	8.529
Gov	150	0.300	0.069	0.101	0.450
Mar	150	0.022	0.032	0.000	0.175

TABLE 3 Benchmark regression results.

Variables	(1)	(2)
Dig	−4.420***	−2.769***
	(−8.42)	(−5.00)
Gdp		−3.636***
		(−8.80)
Cit		10.486***
		(8.90)
Pop		−0.699**
		(−4.48)
Gov		6.397**
		(3.80)
Mar		−5.303**
		(−4.49)
Constant	3.241***	39.953***
	(19.08)	(9.77)
Time-fixed	Yes	Yes
Province-fixed	Yes	Yes
Obs	150	150
R^2	0.102	0.291

Note: t-statistics in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

innovations and integrates advanced technological means to reduce carbon emissions effectively. On the one hand, by building an intelligent carbon emission monitoring and dynamic accounting system, the digital government can accurately track and manage the carbon footprint and ensure the accuracy and real-time nature of carbon emission data. The establishment of this system provides solid data support for quantitative management, target setting, and policy evaluation of carbon emissions (Zhang et al., 2016). The application of big data technology makes it possible to extract valuable carbon emission information from massive data. It provides policymakers in-depth insight and a scientific basis for decision-making by analyzing and predicting carbon emission trends. Introducing artificial intelligence algorithms further optimizes the carbon emission model and improves prediction accuracy.

On the other hand, the digital government not only accelerates the mining and transmission of information through digital technology but also makes the speed of information dissemination much higher and reduces the time lag of information dissemination, which enables it to timely transmit information on carbon emissions and environmental protection of enterprises to the stakeholder groups with information needs (Pei et al., 2018), thus reducing the degree of asymmetry of information and curbing excessive carbon emissions of enterprises (Hu and Jin, 2022). In addition, the digital government strengthens the public's environmental education through the Internet platform, strengthens the interaction between the government and the public, raises society's awareness of the importance of carbon emission reduction, and enables all sectors of society to make smarter environmental protection decisions based on accurate information and participate in carbon emission reduction actions, thus forming an environmental governance system in which the government and the public work together to govern the environment. Therefore, this paper proposes the following research hypotheses.

Hypothesis 1. *Digital government can curb carbon emissions.*

2.2 Mechanisms of digital government on carbon emissions

The optimization and upgrading of industrial structure is one of the key driving forces in transforming the mode of economic growth and achieving high-quality economic development (Ren and He, 2022). First of all, in China, the upgrading of industrial structure is significantly guided and promoted by the government, and the government's governance capacity and service level play a crucial role in promoting industrial upgrading and economic growth. It has been pointed out that the rise of the digital economy provides a new growth engine for transforming industrial structures (Zuo et al.,

TABLE 4 Robustness test results.

Variables	(1)	(2)	(3)	(4)	(5)
	Fe	Fe	Fe	Ols	Re
Dig	−1.369*	−0.155**		−2.769***	−3.153***
	(−2.72)	(−1.99)		(-2.67)	(−4.36)
L.Dig			−3.697***		
			(-9.85)		
Gdp	−0.900***	0.013**	−3.690***	−3.636***	−2.079***
	(−5.68)	(0.15)	(−5.15)	(−4.93)	(−5.84)
Cit	0.713	0.349**	16.238***	10.486***	8.013***
	(1.29)	(1.24)	(5.80)	(3.76)	(6.20)
Pop	−0.596***	−0.020	0.014	−0.699**	−0.758***
	(−11.49)	(−0.76)**	(0.08)	(−2.03)	(−6.83)
Gov	−5.445***	−0.421*	1.108	6.397***	3.630***
	(−13.20)	(−1.94)	(0.52)	(2.86)	(3.75)
Mar	−5.525***	0.160**	−5.171***	−5.303	−13.363***
	(−15.21)	(0.41)	(−7.37)	(−1.38)	(−21.89)
Constant	26.457***	0.749***	34.282***	39.192***	25.318***
	(13.14)	(0.86)	(5.76)	(5.48)	(7.44)
Time-fixed	Yes	Yes	Yes	Yes	Yes
Province-fixed	Yes	Yes	Yes	Yes	Yes
Obs	150	150	120	150	150
R^2	0.499	0.196	0.390	0.292	0.270

Note: t-statistics in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

2020; Li et al., 2021). In contrast, the construction of digital government is regarded as the core strategy to promote the development of the digital economy (Dai and Bao, 2017; Bi and Wang, 2023). Second, digital government optimizes the government's business structure and organizational structure by integrating modern information technology and improving decision-making efficiency and public service quality (Huang, 2020). The digital government utilizes data analysis and data governance to accurately formulate and implement industrial policies and promote the upgrading of industrial structure. Cai (2023) research shows that local governments use big data and information technology to reform government informatization, regulate market order, and promote economic development through industrial policy and platform construction. Again, in utilizing digital technology, the digital government significantly improves the efficiency of information flow between industrial chains and effectively alleviates the problem of information asymmetry, thus breaking down the barriers between industries. This change promotes the operational efficiency of the entire industrial chain and reshapes traditional industries' production processes and development modes by utilizing its unique data resources (Heo and Lee, 2019). In the deep integration of digital technology and traditional industries, the market linkage effect and spillover effect triggered has promoted the transformation and upgrading of industrial structure from low-end to high-end. This process not only eliminates industries with backward production capacity and serious environmental pollution but also spawns several new industries with high value-added and low energy consumption, thus realizing an effective reduction of carbon emissions at the regional level.

The upgrading and transformation of industrial structures significantly impact carbon emissions, and their effect is manifested in two main ways. Firstly, industrial upgrading promotes the transformation from labor- or resource-intensive industries to technology- or capital-intensive industries. This transformation not only optimizes the allocation of production factors and improves production efficiency but also positively reduces carbon emissions by lowering energy consumption and reducing resource waste (Zhao and Yao, 2024). Secondly, the proportion of high-tech and modern service industries has gradually increased with the continuous upgrading of industrial structures. These industries adopt cleaner and low-carbon production methods, such as implementing energy-saving and emission-reduction technologies and green production processes,

TABLE 5 Endogeneity test results.

Variables	(1)	(2)
	Phase I	Phase II
IV	−0.424***	
	(6.07)	
Dig		−4.502*
		(−1.80)
Gdp	0.004	−2.588**
	(0.01)	(−2.50)
Cit	0.133	1.225***
	(−0.05)	(4.62)
Pop	−0.194***	−0.958*
	(−7.92)	(−1.69)
Gov	−0.006	−3.609**
	(−0.05)	(−2.31)
Mar	1.890**	−4.524***
	(2.29)	(−3.12)
Constant	10.66**	31.028***
	(2.34)	(2.99)
Obs	120	120
R^2	0.306	0.248
C-D Wald F		36.84
Stock-Yogo		(16.38)
P-value		0.000

Note: t-statistics in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

which may be important in reducing carbon emissions (Zhou and Luo, 2021). Industrial structure upgrading provides strong support for realizing the goals of low-carbon development and environmental protection by promoting changes in production methods and the application of technological innovations. Therefore, the following hypothesis is proposed:

Hypothesis 2. *Digital government construction suppresses carbon emissions by promoting industrial structure upgrading.*

By internalizing digital technologies in its transformation, the digital government has achieved the integration of institutions and organizations and the synergistic re-engineering of processes (Lee et al., 2016), which not only opens up paths for holistic governance and establishes value objectives but also provides a solid governance foundation for the empowerment of green technological innovation. On the one hand, the digital government has also significantly promoted the development of green technology by providing policy incentives and financial support. Accurate data analysis and tracking enable governments to design better and implement policy incentives such as tax incentives, subsidies, and green credits, ensuring that these incentives effectively promote the development of green technologies. Digital platforms streamline the process of applying for and disbursing funds, increasing the efficiency of their use and reducing corruption and waste. For example, the online application and approval system allows for the rapid processing of funding applications for environmental projects and ensures the timely availability of funds. On the other hand, the digital government breaks down multiple information barriers and reshapes administrative processes through collaborative governance on digital platforms, empowers the public and market players by establishing an information-sharing mechanism, reduces transaction costs and administrative burdens, enhances government efficiency, and improves the provision of services to provide a favorable business environment and solid institutional safeguards for market players to carry out green technological innovations (Liao, 2020), and thus stimulates the vitality of green technological innovations (Xiong and Dai, 2024).

The role of green technological innovation in reducing carbon emission intensity is mainly reflected in the following three aspects: first, green technological innovation promotes changes in the pattern of energy production and consumption and reduces dependence on fossil fuels. Specifically, renewable energy technologies, including solar energy, wind energy, and bioenergy, as a solution to replace traditional high-carbon energy sources (such as coal, oil, and natural gas), have effectively reduced greenhouse gas emissions, thereby reducing carbon emission intensity. Second, green technology innovation at the enterprise level improves clean production technology, reduces production costs, enhances enterprise competitiveness, and generates significant spillover effects. Studies have shown that green technology innovation can positively impact other areas by enhancing corporate image, attracting investment, and obtaining government policy support (Dai et al., 2022). For example, financial subsidies, as a means of incentivization, can strengthen enterprises' green technology innovation activities and thus reduce their carbon emissions. Finally, green technological innovation promotes green production by enterprises by developing and promoting environmentally friendly products. Enterprises adopt low-carbon materials and green technologies and adjust their production structure to implement cleaner production. In addition, green technology innovation also realizes the reuse of industrial waste through synthetic and biological transformation, greatly improving resource utilization and effectively promoting energy conservation, consumption reduction, and green low-carbon development (Guo et al., 2022). In summary, green technology innovation is key to reducing carbon emission intensity by changing the energy use pattern, enhancing enterprise competitiveness, and promoting green production. Based on the above analysis, the following research hypotheses are proposed:

Hypothesis 3. *Digital government construction suppresses carbon emissions by promoting green technological innovation.*

This paper develops according to the research idea of "problem posing-theoretical elaboration-empirical analysis-conclusion and recommendation", and explores the two core issues of whether and how digital government can influence carbon emissions. The research framework is shown in Figure 1.

TABLE 6 Mechanism test results.

Variables	(1)	(2)	(4)
	C	Ind	Tec
Dig	−2.769***	1.305**	1.773**
	(−5.00)	(2.83)	(3.53)
Gdp	−3.636***	−0.056	2.089***
	(−8.80)	(−0.19)	(19.09)
Cit	10.486***	1.514	−3.952***
	(8.90)	(1.46)	(−7.96)
Pop	−0.699**	0.094	−0.068
	(−4.48)	(1.26)	(−0.84)
Gov	6.397**	1.952**	6.935***
	(3.80)	(3.17)	(15.05)
Mar	−5.303**	14.271***	9.231***
	(−4.49)	(14.64)	(15.54)
Constant	39.953***	−0.812	−14.579***
	(9.77)	(−0.23)	(−22.07)
Time-fixed	Yes	Yes	Yes
Province-fixed	Yes	Yes	Yes
Obs	150	150	150
R^2	0.291	0.628	0.638

Note: t-statistics in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

3 Study design

3.1 Measurement modeling

3.1.1 Benchmark model

The following econometric model is set up to examine the impact of digital government construction on carbon emissions:

$$Cit = \beta 0 + \beta 1Digit + \beta 2\sum Xit + \mu i + \xi t + \varepsilon it \quad (1)$$

Where Cit refers to the explanatory variable carbon emission, which indicates the total carbon emission of province i in year t. Digit denotes the explanatory variable digital government, which indicates the level of digital government construction of area i in year t. The coefficient β1 is the effect of digital government carbon emissions. ∑Xit is a series of control variables, and the coefficient β2 is the effect of control variables. μi and ξt are the area fixed effects and time fixed effects, respectively. εit is the random error term, and β0 is the constant term. In this paper, regressions are conducted using a fixed effects model, controlling for province and time effects.

3.1.2 Mechanism testing

This paper mainly relies on the two-step mediation effect model proposed by Jiang (2022) to test whether digital government will have an impact on carbon emissions through the channels of industrial structure upgrading and green technology innovation, and the model is constructed as follows:

$$Mvit = \theta 0 + \theta 1Digit + \theta 2\sum Xit + \mu i + \xi t + \varepsilon it \quad (2)$$

In Equation 2, Mvit is the explanatory variable, and the mediating variables industrial structure upgrading and green technology innovation are indicated, respectively. The meanings of the remaining variable symbols are the same as in Equation 1.

3.2 Variable selection

3.2.1 Explained variables

3.2.1.1 Carbon Emission

Drawing on the practice of Ha and Huang (2024), this paper adopts carbon emission intensity (CO_2/GDP) to more accurately reflect carbon emissions. This is done by multiplying the consumption of each of the eight fuels, including coal, crude oil, and coke, by their corresponding carbon emission coefficients and calculating the total carbon emissions of each province (autonomous region and municipality directly under the central government) in China between 2017 and 2021. Subsequently, the carbon emission intensity was derived by comparing the total emissions with the gross regional product. This approach can exclude the potential

TABLE 7 Heterogeneity test results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Eastern and central	Western	High government transparency	Low government transparency	Strong environmental regulation	Weak environmental regulation	High level of digital government	Low level of digital government
Dig	−0.610**	−1.957	−4.466**	0.018	−4.891**	−0.058	−7.981***	−0.443
	(−2.05)	(−1.44)	(−2.54)	(0.01)	(−2.42)	(−0.02)	(−3.22)	(−1.37)
Gdp	−1.706***	−3.646***	−3.441***	−2.429**	−3.607***	−4.464***	−5.943***	−1.478***
	(−9.36)	(−3.60)	(−3.50)	(−2.18)	(−4.33)	(−4.93)	(−4.28)	(−7.12)
Cit	1.833**	18.421***	11.451***	7.167	12.222***	14.546***	22.285***	2.946***
	(2.06)	(4.64)	(2.84)	(1.50)	(3.29)	(3.70)	(4.24)	(3.86)
Pop	0.177*	−0.876*	−1.231**	−0.005	−1.677***	1.046*	−1.796***	−0.084
	(1.96)	(−1.76)	(−2.27)	(−0.01)	(−2.96)	(1.85)	(−2.81)	(−0.47)
Gov	0.528	16.093***	1.913	1.706	−1.019	12.585***	11.289***	0.180
	(0.77)	(3.29)	(1.21)	(0.95)	(−0.46)	(3.32)	(2.90)	(0.14)
Mar	2.323	−36.202***	−7.763	−23.676	−10.761**	−43.552***	−23.258*	−1.756
	(1.60)	−1.957	(−1.59)	(−1.49)	(−2.06)	(−2.69)	(−1.76)	(−0.78)
Constant	17.641***	34.318***	41.937***	44.115***	49.101***	30.521***	66.000***	16.599***
	(12.00)	(3.53)	(3.74)	(6.69)	(4.40)	(4.35)	(4.42)	(4.63)
Time-fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province-fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	57	93	85	65	70	80	66	84
R2	0.788	0.401	0.355	0.146	0.476	0.311	0.477	0.202

Note: t-statistics in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01.

interference of economies of scale in assessing environmental quality.

3.2.2 Explanatory variables

3.2.2.1 Digital Government

Constructing a digital government evaluation index system is a complex process, and this paper focuses on constructing digital government evaluation indexes based on the TOE theory. As a classic theoretical framework for explaining the adoption and diffusion of information technology, the TOE theory (Technology-Organization-Environment Framework), with its comprehensiveness, dynamism and adaptability, makes it an ideal choice for constructing digital government evaluation indexes makes it an ideal choice for constructing digital government evaluation indicators. Covering the three interrelated dimensions of technology, organization and environment, the theory is able to comprehensively consider the technological foundation, organizational structure and external environment of digital government construction, so as to assess its development level in a more comprehensive way, thus ensuring the scientific and objective nature of the evaluation indicators. When selecting specific secondary indicators, this paper synthesizes the research results of Tan et al. (2019), Han (2019) and other scholars, and finally determines nine secondary indicators, which are shown in Table 1. The weights of the digital government indicators are mainly determined by the entropy method, because the entropy method is not subject to the influence of the subjective will of the evaluation body, and it is based entirely on the information entropy value of the indicator data itself for the assignment of weights. This makes the weight allocation more objective and fair, and avoids the interference of human factors.

3.2.3 Mediating variables

3.2.3.1 Industrial structure upgrading

Industrial structure upgrading is a key phenomenon in economic development, reflecting the dynamic evolution of industrial structure from low value-added and low-technology levels to high value-added and high-technology levels. In this process, the trend of economic servitization is gradually increasing, and the proportion of output value of the tertiary industry relative to that of the secondary industry is rising, marking the realization of industrial transformation and upgrading. Drawing on the research method of Wang and Xu (2024), the process of advanced industrial structure is measured by comparing the proportion of output value of the tertiary industry with that of the secondary industry. The increase in the value of this indicator reflects the optimization of the economic structure and reveals the change of the dominant industry in society.

3.2.3.2 Green Technology Innovation

In this paper, compared with the number of green patent applications, the number of green patent grants reflects the actual improvement in the level of green technological innovation in a region. Therefore, we take the natural logarithm of the number of green patents granted as a measure of green technological innovation based on the practice of Li and Xiao (2020).

3.2.4 Control variables

In addition to the key variables mentioned above, variables that may generate homoscedastic errors are eliminated as much as possible. Finally, the urbanization rate (Cit, %), total population (Pop, ten thousand people), the degree of government intervention (Gov, %), the level of development of the technology market (Mar, %), and economic growth (Gdp, %) are selected as control variables. Among them, the urbanization rate is measured by the percentage of the urban population and the total population. The total population is used to calculate the province's total population at the end of the year. The ratio of fiscal expenditure and GDP measures the level of government intervention. The ratio of technology market turnover and GDP measures the level of technology market development. The growth rate of GDP measures economic growth.

3.3 Data sources

This paper selects data from 30 provincial-level administrative regions in China (excluding Taiwan, Hong Kong, Macao and Tibet) from 2017 to 2021 as sample data. The years 2017–2021 were chosen for this paper because 2017 is one of the key years for digital government building in China. Digital government was first proposed by President Xi Jinping in 2017, and the Chinese government released a series of policy documents to promote the construction of digital government in this year. The data for the period of 2017–2021 is relatively new, which can better reflect the latest progress and effect of the current digital government construction, and improve the timeliness and relevance of the study. Moreover, during this time period, China's digital government construction and carbon emission data records are more complete, which is convenient for empirical analysis. Carbon emissions data are from the China Ecological Environment Statistics Annual Report. Digital government data are from the China Statistical Yearbook and government websites. Data on industrial structure upgrading are from the China Statistical Yearbook, and data on green technology innovation are from the China Research Data Service Platform (CNRDS). Relevant control variables are from the China Statistical Yearbook and Global Statistical Data Analysis Platform database (EPS). The statistical software used in this paper is statat16.0.

Table 2 shows the descriptive statistics of the main variables. The mean value of the explanatory variable Carbon Emission (C) is 1.810, and the minimum and maximum values are 0.196 and 10.556, respectively, which indicates that carbon emission is more uneven among regions in China. The mean value of the core explanatory variable Digital Government (Dig) is 0.324, and the minimum and maximum values are 0.064 and 0.663, respectively, indicating differences in the level of digital government in different periods and regions. In addition, the variables of industrial structure upgrading (Ind) and green technological innovation (Tec) also differ in different degrees among provinces in China. The statistical results of other variables will not be repeated.

4 Empirical findings

4.1 Benchmark regression results

Before conducting the benchmark regression, this paper first conducts the multicollinearity test on the explanatory variables and control variables, and the results show that the variance inflation factors are all at less than 10, indicating that there is no multicollinearity problem between the explanatory variables and the control variables. Further F-test and Hausman test were conducted, and the F-test showed that the P-value was 0, and the F-test was 0. Test results show that the P-value is 0, so the hypothesis of mixed regression model is rejected and fixed effects are selected; at the same time, the Hausman test is applied to the random effect model and fixed effect model to select the random effect model and the fixed effect model. At the same time, the Hausman test was applied to select the random effect model and the fixed effect model, and the Hausman test results showed that Prob > chi2, the hypothesis that the model is a random effect should be rejected, and it should be verified again that the fixed effect model should be established. The results of the Benchmark Regression of Digital Government Construction on Carbon Emissions are shown in Table 3. Among them, Column (1) does not take into account the effect of control variables, and it is found that the regression coefficient of the variable Digital Government Construction is negative and significant at a 1% level, which indicates that Digital Government Construction is conducive to the suppression of carbon emissions. Based on Column (1). Column (2) incorporates control variables, and further controls for time-fixed and province-fixed effects and finds that the regression coefficient of digital government on carbon emissions is still significantly negative at the 1% statistical level. This indicates that digital government construction significantly inhibits carbon emissions throughout the sample period, verifying research hypothesis H1.

4.2 Robustness tests

4.2.1 Substitution of explanatory variables

This paper draws on the research of Guo Jinhua and other scholars (Guo et al., 2024) to take the natural logarithm of carbon emissions and use it as a proxy variable for robustness testing. The regression results are shown in column (1) of Table 4. The empirical results show that the coefficient of the variable digital government is still negative at the 10% significance level, which indicates that the construction of digital government can inhibit carbon emissions, which is consistent with the conclusions obtained in the basic regression results and the findings of this paper are robust and reliable.

This paper also borrows from Shen and Fan (2023) to measure the carbon emission efficiency by using the super-efficient SBM model with non-expected output and the entropy method. And it is used as an explanatory variable for the robustness test. The results are shown in column (2) of Table 4, the regression coefficient of the variable digital government is significantly negative at 1% statistical level, which is consistent with the conclusion obtained from the basic regression results, and the conclusions of this paper are robust and reliable.

4.2.2 One-period lagged explanatory variables

Considering that there may be a lag effect in the process of digital government construction, i.e., the suppression of carbon emissions in the current period is brought about by the effect of digital government construction in the previous period, this paper adopts the approach of replacing the original explanatory variables by lagging the explanatory variables by one period to do the robustness test. The empirical results are shown in column (3) of Table 4. After lagging the explanatory variables by one period, there is still a significant negative correlation between digital government and carbon emissions, indicating that the empirical findings are still robust after considering the lag of digital government construction.

4.2.3 Replacement of the baseline regression model

Considering the non-robustness of the findings that may result from the modeling setup, this paper employs the Ordinary Least Squares (OLS) regression model and random effects model as an alternative to the originally used fixed effects model for the robustness analysis. The regression results are shown in column (4) and column (5) of Table 4. The empirical results show a negative relationship between the core explanatory variable digital government and carbon emissions, which is statistically significant at the 1% level, and the findings of this paper are robust.

4.3 Endogeneity tests

In this study, considering that the relationship between digital government construction and carbon emissions may be co-influenced by unobservable factors, leading to potential omitted variable bias, this paper adopts an instrumental variable approach to address the endogeneity issue. The selection criterion of instrumental variables is that they should be significantly related to digital government construction while having no direct effect on the disturbance term. Based on this criterion, this study selected the lagged one period (L. Dig) of the level of digital government construction as the instrumental variable (IV) and re-tested it using the two-stage least squares regression (2SLS) method. The design advantage of this instrumental variable is its independence. It can be formed without additional external variables, thus effectively preventing unforeseen effects that other potential instrumental variables may have on the explained variables.

The probability of under-identification (P-value) of the instrumental variable is zero, indicating that there is no under-identification. The Cragg-Donald Wald F-statistics used to diagnose the strength of the instrumental variables were all significantly higher than the critical value of 16.38 set at the 10% significance level, thus strongly excluding the possibility of weak instrumental variables. Together, the results of these statistical tests ensure that the instrumental variables approach was appropriately and reliably applied in this study. The results of the 2SLS first-stage regression for instrumental variables are shown in column (1) of Table 5. The 2SLS first-stage regression coefficients of instrumental variable IV are negatively correlated with the variable numerical government at the 1% significance level, indicating that the instrumental variables were selected logically. Column (2) shows the second-stage regression results of the 2SLS of instrumental variable IV, and the variable digital government is negatively correlated with carbon emissions at the 1% significance level, which indicates that digital government can significantly suppress carbon emissions. By applying the instrumental variable method to re-estimate the model, the obtained regression results are consistent with the original benchmark regression results, indicating that the conclusions of this paper are still valid after considering the endogeneity problem.

4.4 Mechanism tests

The results in column (2) of Table 6 show that the impact of digital government on industrial structure upgrading is positive with a regression coefficient of 1.305, which passes the significance test at the 5% level. The results in column (3) of Table 6 show that the effect of digital government on green technology innovation is positive with a regression coefficient of 1.773, which passes the significance test at the 1% level. This indicates that industrial structure upgrading and green technology innovation play a mediating role in the relationship between digital government and carbon emissions, and digital government indirectly affects carbon emissions by improving industrial structure upgrading and promoting green technology innovation, and the research hypotheses H2 and H3 are verified.

4.5 Heterogeneity tests

4.5.1 Heterogeneity analysis of geographical areas

Given the vastness of China and the significant differences in the level of economic development, industrial structure, resource endowment, and policy implementation, the eastern and central regions are usually more economically developed. While the eastern and central regions are usually more economically developed, with an early start in digital government construction, relatively mature technology applications, and relatively well-developed environmental governance systems, the western regions may face more development challenges, such as lagging infrastructure development and talent shortages. In order to explore the differences in the impact of digital government on carbon emissions in different regions, this study divides the sample into eastern central and western parts for regression analysis. As shown in columns (1) and (2) of Table 7, the regression results reveal significant regional effects: the relationship between digital government and carbon emissions is negative and significant at the 5% statistical level in the eastern and central regions. In the western region, the regression coefficient between digital government and carbon emissions did not pass the significance test. This finding is consistent with the suggestion that the dampening effect of digital government on carbon emissions is more significant in the eastern and central regions. Possible explanations include the fact that the eastern and central provinces have more developed economies, better information infrastructure, stronger governmental governance, more optimized industrial structure, and higher public awareness of environmental protection, which together promote the application of digital government in efficiently monitoring and managing carbon emissions, thus achieving more significant carbon emission reduction.

4.5.2 Heterogeneity analysis of government transparency

In exploring the impact of digital government construction on carbon emissions, analyzing the heterogeneity of government transparency is particularly crucial. The openness of information and the transparency of government operations are the core elements that optimize the allocation of information resources and enhance the reliability and accuracy of market information, which play a significant role in reducing transaction costs and enhancing market efficiency (Li et al., 2017). Through heterogeneity analysis, this study examines the differences in the inhibiting effect of digital government construction on carbon emissions under different government transparency contexts. Drawing on the research results of Yi Xuan and Hou Jianing, the transparency index in the Chinese Government Transparency Index Report published by the Chinese Academy of Social Sciences is used as a proxy variable to measure government transparency (Yi and Hou, 2018). The classification of government transparency is based on the transparency index scores, dividing the sample provinces into two groups: high transparency and low transparency. Samples with scores above the average are identified as the high transparency group, while those below the average are identified as the low transparency group. The split-sample regression analysis in columns (3) and (4) of Table 7 shows that in the sample group with higher government transparency, the negative association between digital government and carbon emissions is statistically significant at the 5% level.

In contrast, The regression coefficients between digital government and carbon emissions do not pass the significance test in the sample group with lower government transparency. This result reveals that the inhibitory effect of digital government on carbon emissions varies across different levels of government transparency, especially in areas with higher government transparency. The inhibitory effect of digital government on carbon emissions is more significant. Highly transparent local governments mean that information is more open, and the public can more easily access data and policy information on carbon emissions. By making data more transparent, digital government enables more accurate and timely monitoring and reporting of carbon emissions, facilitating public and third-party monitoring and thus promoting the implementation of carbon reduction measures.

4.5.3 Heterogeneity analysis of the level of digital government construction

In this paper, the sample is divided into two intervals bounded by the ranked average of the total digital government scores, which are the provinces with the top 50% of the digital government construction level and the provinces with the bottom 50% of the digital government construction level. The regression analysis of the grouped samples in columns (5) and (6) of Table 7 shows that the negative correlation between digital government and carbon emissions is statistically significant at a significance level of 5% in the sample group with a higher level of digital government construction. In contrast, the regression coefficient between digital government and carbon emissions did not pass the significance test in the sample group with lower digital government construction. The reason for this phenomenon may be due to the fact that regions with a higher level of digital government construction have developed a more mature and efficient digital infrastructure, which can effectively monitor and manage carbon emissions; at the same time, the policy implementation in these provinces is stronger and more efficient, which enables better implementation of emission reduction measures. In addition, in terms of resource allocation, these provinces also prioritize environmental protection and emission reduction. In contrast, provinces with a lower level of digital government building may fail to demonstrate a significant correlation between digital government building and carbon emissions due to insufficient infrastructure, ineffective policy implementation, outdated economic structure, lack of green technology and innovation capacity, and inappropriate resource allocation.

4.5.4 Heterogeneity analysis of the intensity of environmental regulation

External environmental policies also have an impact on carbon emissions. Based on this, the samples are regressed into two groups based on the mean of provincial environmental regulation intensity. The regression analysis of the grouped samples in columns (7) and (8) of Table 7 shows that the negative correlation between digital government and carbon emissions is statistically significant in the sample group with higher environmental regulation intensity, with a significance level of 1%. In contrast, the regression coefficient between digital government and carbon emissions did not pass the significance test in the sample group with lower environmental regulation intensity. This phenomenon may be due to the fact that in regions with higher environmental regulation intensity, the government implements more stringent environmental policies to push firms to adopt environmental protection measures, and the efficient regulation and information transparency of digital government enhances the effectiveness of these policies. Therefore, the negative correlation between digital government and carbon emissions is statistically significant. In regions with weaker environmental regulations, on the other hand, due to the lack of sufficient policy promotion and public participation, enterprises have insufficient incentives to reduce emissions, and the abatement potential of the digital government fails to be fully utilized, resulting in a non-significant correlation between it and carbon emissions. This suggests that the strength of environmental regulation has an important impact on the role of digital government in reducing emissions.

5 Conclusion and implications

In light of the world's growing concern for environmental protection and sustainable development, particularly with China's vigorous promotion of ecological civilization construction, this paper investigates the impact and intrinsic mechanisms of digital government construction on carbon emissions using panel data from 30 provinces in China from 2017 to 2021. The conclusions are as follows: first, digital government construction can significantly curb carbon emissions, and the empirical results remain robust after considering endogeneity issues and undergoing various robustness tests. Second, digital government construction can suppress carbon emissions by upgrading industrial structures and promoting innovation in green technology. Third, the inhibiting effect of digital government on carbon emissions is more pronounced in eastern and central provinces, provinces with higher levels of government transparency, higher levels of digital government development, and higher intensity of environmental regulation.

This study has the following insights: (1) Deepen the construction of digital government and improve its effectiveness. Increase financial investment, prioritize the development of digital infrastructure, improve information transmission speed and coverage, and provide a solid technical foundation for digital government construction. Strengthen data governance, establish a sound data sharing and opening mechanism, improve data quality and utilization efficiency, and provide accurate data support for carbon emission management and decision-making. (2) Optimize industrial structure and promote low-carbon development. Formulate differentiated industrial policies for different regions and stages of industrial development to guide industries in the direction of low-carbon development. Relying on the existing industrial foundation, cultivate and develop green industrial clusters, form industrial chain synergies, and reduce carbon emission intensity. (3) Encourage green technological innovation to enhance the power of emission reduction. Increase investment in research and development, increase investment in green technology research and development, encourage enterprises and scientific research institutions to carry out green technology innovation, and promote the research, development and application of low-carbon technologies. Improve the incentive mechanism, establish a sound incentive mechanism for green technological innovation, and encourage enterprises and individuals to carry out green technological innovation through tax concessions and financial subsidies. (4) Strengthen regional differentiation strategies to narrow the development gap. In the western region, focus on strengthening the construction of digital infrastructure, upgrading the level of information sharing and technology exchange, and narrowing the gap with the eastern region. In the eastern and central regions, focus on developing green technologies and industries, exploring market-based mechanisms such as carbon emissions trading, and playing a leading role as a model.

The research shortcomings of this paper are mainly in the following aspects. First, the study is only based on provincial panel data from 2017–2021, which is a relatively short period and may only partially reflect the long-term impact of digital government construction on carbon emissions. Future research could collect data over a more extended period to analyze the long-term impact of digital government construction on carbon emissions and explore its dynamic trends. Second, the study has explored the intrinsic mechanism of how digital government can curb carbon emissions by upgrading industrial structures and promoting green technology innovation. However, it may fail to fully reveal all the relevant paths of action and mediating variables. In-depth research on the mechanisms by which digital government affects carbon emissions, including more mediating and moderating variables, is needed to reveal more complex paths of action. Again, digital government construction involves the synergistic cooperation of multiple government departments and levels, and the study may have yet to thoroughly examine the impact of synergistic effects among different government departments on carbon emissions, as well as the spatial spillover effects of digital government on carbon emissions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JY: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by the National Social Science Foundation Youth Program (17CGL013).

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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