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Digital governance and natural resource efficiency: evidence from China

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ABSTRACT
Advances in digital governance significantly enhance natural resource efficiency (NRE), supporting regional sustainable development. This study adopts the implementation of digital governance construction (DGC) policies as a quasi-natural experiment by analysing longitudinal data from 281 Chinese cities (2010–2021) using robust methodologies, including the synthetic control method, difference-in-differences (DID) and propensity score matching DID. Findings reveal that DGC policies improve NRE through regional technological innovation and government support, moderated by urban ecological resilience. Regional heterogeneity is evident across digitisation, industrial structure, resource endowment, transparency and market access. Tailored strategies to regional characteristics, leveraging these dimensions can optimise DGC policies for sustainable urban development and ecological welfare. This study contributes to regional studies and environmental management literature by innovatively framing digital governance as a mechanism to improve NRE and proposing a dynamic heterogeneity analysis framework that advances the understanding of regional policy impacts in the digital era.

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Digital governance; natural resource efficiency; urban ecological resilience; regional heterogeneity

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1. Introduction

In an era of digital transformation, the governance of natural resources is undergoing fundamental redefinition – not merely shaped by physical scarcity but increasingly driven by a growing mismatch between digital capability and institutional responsiveness. The context of China offers a particularly salient case. As the world's largest developing economy and carbon emitter, it faces the dual pressure of sustaining economic growth while mitigating severe ecological degradation. In response, the Chinese central government has advanced a policy paradigm of 'ecological civilization', which aims to integrate environmental concerns into the heart of governance and planning.

Within this paradigm, digital governance construction (DGC) has emerged as a key reform strategy. The 2018 'Digital China' Strategy Outline and subsequent State Council directives set ambitious goals for digital integration across government functions, including environmental regulation, urban planning and public service delivery (National Development and Reform Commission, 2018). Pilot cities such as Hangzhou and Shenzhen have deployed integrated digital platforms to monitor water, energy and emissions in real time, generating measurable improvements in natural resource efficiency (NRE). In contrast, many inland and resource-dependent cities still rely on static reporting systems and fragmented data silos, leading to inefficiencies, policy inertia and environmental degradation. This divergence raises two central and timely questions: (1) How does DGC influence NRE in the context of Chinese cities? (2) How do regional disparities in digital capacity, institutional quality and ecological resilience shape this relationship?

This question is especially pertinent in China, where regional inequality remains deeply entrenched. Coastal cities enjoy advanced digital ecosystems and open market access, while interior regions often lag in both technological infrastructure and environmental governance. Moreover, China's industrial economy continues relying heavily on resource-intensive sectors such as steel, coal and cement, many of which are

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concentrated in regions with weak institutional enforcement. Despite national commitments to peaking carbon emissions by 2030 and achieving carbon neutrality by 2060, implementation varies widely at the regional level, making China a natural laboratory to explore how digital policy frameworks interact with uneven territorial conditions to affect sustainability outcomes.

A growing body of research has examined the drivers of NRE, including green technology adoption (Shah et al., 2024), energy transition (Fan et al., 2025) and environmental regulation (Wang et al., 2021). Meanwhile, digital governance has been recognised for improving administrative efficiency, transparency and citizen engagement (Elbahnasawy, 2021; Ma & Zheng, 2019). However, few studies examine how DGC affects resource efficiency in an institutional environment marked by spatial fragmentation, sectoral rigidity and asymmetric policy capacity, as is the case in many parts of China.

This oversight leaves two key research gaps. First, empirical studies rarely explore how digital governance affects NRE through mechanistic pathways, such as financial development, technology deployment or administrative coordination. Second, the regional heterogeneity of digital governance effects, especially across cities with different levels of digitisation, transparency and ecological resilience, remains poorly understood. Bridging these gaps is essential for both theoretical development and effective policy design.

To address these gaps, this study treats the implementation of DGC policies in 2018 as a quasi-natural experiment and investigates their effects on NRE using panel data from 281 Chinese cities between 2010 and 2021. We adopt a rigorous mixed-methods econometric framework that combines the synthetic control method (SCM), difference-in-differences (DID) and propensity score matching DID (PSM-DID) to ensure robust causal inference. In addition to identifying the average treatment effect of DGC, we explore mediating mechanisms – such as digital technology diffusion, financial development and government participation – and test the moderating role of urban ecological resilience.

This study contributes to both theoretical advancement and practical governance strategy in the domains of regional science and environmental management. Theoretically, we bridge two traditionally siloed literatures of digital governance and NRE by conceptualising DGC as a structural and regionally contingent driver of sustainable resource use. Drawing on resource dependence theory, dynamic capabilities theory and institutional theory, we develop a novel analytical framework that highlights how digital governance improves NRE through mediating mechanisms, while being moderated by urban ecological resilience. This contributes to a more granular understanding of how policy effects vary across heterogeneous regional contexts and offers a dynamic, mechanism-based lens to interpret governance outcomes in the digital era.

Practically, this study offers a diagnostic and actionable roadmap for policymakers navigating sustainability transitions. First, we provide empirical evidence that DGC yields the greatest improvements in NRE in cities with advanced digital infrastructure, high transparency and strong market access, indicating that tailored policy sequencing is critical for less-developed regions. Second, we offer mechanism-specific guidance: cities can enhance NRE by investing in AI-driven environmental platforms, building interoperable data ecosystems, adopting performance-based fiscal instruments and embedding nature-based solutions into digital platforms. Finally, we highlight the amplifying role of urban ecological resilience, which functions as a policy multiplier, suggesting that investments in green infrastructure and adaptive urban planning should be embedded into digital governance strategies. In doing so, we move beyond generic policy recommendations and provide city-specific pathways for using DGC to promote sustainable and equitable resource governance.

2. Theory and hypothesis development

2.1. Theoretical background

NRE is defined as the capability to transform natural resources into economic value within a specific period, serving as a critical measure of resource utilisation efficiency (Shah et al., 2024). Notwithstanding the concept's multidisciplinary nature, scholars widely acknowledge that NRE is subject to various regional factors' influences, including technological advancements, industrial structures, population dynamics and consumption patterns. At the regional level, NRE is unevenly distributed over space. The theoretical underpinning for this study draws from resource dependence theory, dynamic capabilities theory and institutional theory, which collectively provide the theoretical foundation for analysing how regional-level technological, financial and governmental factors, alongside ecological resilience, shape the relationship between digital governance and NRE. Three theoretical perspectives offer a nuanced understanding of the regional-level determinants of NRE.

Resource dependence theory (Wang et al., 2025) and Dynamic capabilities theory (Fainshmidt et al., 2019) are complementary frameworks that explain how organisations access and utilise resources to competitive advantage. Resource dependence theory posits how organisations rely on external resources and how they manage those dependencies to sustain operations effectively. Applied to cities, the argument asserts that organisations depend on critical external resources to survive and function. For example, organisations that are more dependent on the government will engage in government advocacy to take business action. Following this theoretical line, we posit that cities leveraging external resources from local regions, such as digital platforms and technological innovations, are better positioned to manage natural resources efficiently and enhance NRE. Cities that effectively harness external resources, such as digital platforms and technological innovations, are better equipped to manage their natural resources and improve NRE. Conversely, regions with inefficient industrial structures often prioritise short-term economic growth over sustainable resource management, leading to resource depletion and environmental degradation.

Dynamic capabilities theory (DCT) provides an insightful framework for understanding how a city can leverage digital governance to enhance resource efficiency. DCT emphasises the importance of developing, integrating and reconfiguring both internal and external competencies in response to dynamic environments, thereby maintaining a competitive advantage. DCT is usually applied to firms' strategic management, while DGC is also widely applied to city-level research, such as dynamic capabilities of a smart city, government dynamic capabilities and smart city (Barrutia et al., 2022). In the context of this study, DCT emphasises the importance of city dynamic adaptation in utilising digital technologies and financial innovations to improve NRE. The structure of the regional economy and its industries significantly impact NRE. High-tech industries typically exhibit higher NRE due to their focus on innovation and optimisation of resource use, while traditional industries, such as heavy manufacturing and agriculture, tend to have lower NRE (Hong et al., 2019). As a result, regions with a higher concentration of modern industries are generally more efficient in their resource utilisation. In contrast, economies that rely on inefficient industrial structures tend to sacrifice long-term resource sustainability for short-term economic gains, leading to resource depletion and environmental degradation.

Institutional theory provides an additional lens to examine how external pressures from an organisation's embedded environment can influence the adoption of certain practices and actions, including formal institutions (laws, rules and regulations) and informal institutions (culture, norms and values) (North, 1990). Thus, government policies, regional characteristics and the availability of local resources also affect NRE. Environmental policies, such as resource conservation regulations, can promote the efficient use of resources, while regional factors of geographic location and resource endowments, influence how effectively resources are utilised in local regions (Wang et al., 2021). These factors interact in complex ways, collectively shaping the overall efficiency of natural resource use. Demographic factors, such as population size and consumption behaviour, further shape NRE. Rapid population growth often leads to unsustainable resource consumption, including increasing demand for natural resources wastes (Khan et al., 2022). Conversely, environmentally conscious consumption behaviours, driven by increasing sustainability awareness, can guide efficient resource use and conservation (Liang et al., 2024). As such, sustainable consumption patterns play a crucial role in mitigating resource wastage and enhancing NRE.

This study adopts an integrative theoretical approach to explore how DGC can promote NRE in the consideration of regional heterogeneity. While prior studies have largely investigated the economic and technological impacts of DGC, insufficient attention has been given to its influence on NRE. This study seeks to address this gap by exploring the regional heterogeneity of technological, financial and governance factors through which DGC affects NRE. Unlike previous studies, which provide a static analysis of DGC's influences NRE, our study sheds light on key mediating factors at the regional level, including technological advancement, financial innovation and government participation, that shape the relationship between DGC and NRE. By addressing these gaps, this study provides a comprehensive framework for understanding how DGC contributes to sustainable resource management in the digital era. Table 1 highlights the key differences between this study and previous research, emphasising the novelty of our theoretical conceptualisation and its focus on mediating factors that link DGC with NRE.

Table 1. Comparison table: differences between this study and previous research.

Comparison dimension	This study	Previous studies
Research methodology	Utilises rigorous econometric methods such as SCM, DID and PSM-DID to empirically assess the impact of DGC on NRE.	Predominantly qualitative research or simple regression analyses, with limited use of quasi-experimental methods to explore causal effects of DGC policies on resource management (Boon et al., 2025)
Data sources	Analyses data from Chinese prefecture-level cities between 2010 and 2021, focusing on the impact of DGC on NRE before and after policy implementation.	Often rely on macroeconomic data or cross-country comparisons, with limited attention to regional-level impacts of policy interventions (Yang et al., 2024).
Research focus	Investigates the mechanisms through which DGC influences NRE, with a particular focus on technological progress, financial development and government participation as mediating factors.	Primarily focuses on the economic growth, technological innovation and governance improvements brought by DGC, with limited attention to its direct effects on resource efficiency (Lee et al., 2023; Hu & Li, 2024; Zhang & Du, 2022).
Innovative contributions	Introduces DGC as a quasi-natural experiment, providing a comprehensive analysis of its dynamic impact on NRE, and explores the heterogeneous effects of policy across different regions and industries.	Few studies have examined the dynamic effects of DGC on NRE, and they lack an in-depth analysis of policy heterogeneity across regions and industries (Elbahnasawy, 2021).
Study subjects	Focuses on the variation in NRE across Chinese cities following DGC implementation, with particular attention to how digitalisation levels, government financial transparency, and market access mediate policy outcomes.	Most studies focus on national-level economic and governance effects, with a limited examination of regional disparities and differences in resource utilisation efficiency.
Policy implications	Provides policy recommendations tailored to different regions and industrial structures, aiming to improve resource management through digital technologies, financial support and government participation.	Previous studies focus on general governance improvements and economic growth, with little attention to specific digital strategies for resource management (Bannister & Connolly, 2014; AlGhamdi et al., 2020; Zhu et al., 2023b).
Theoretical contributions	Fills a gap in the literature by linking digital governance with NRE, identifying key mechanisms such as technological, financial and governmental factors in driving sustainable resource management.	Previous literature has explored the relationship between DGC and economic growth or industrial innovation but lacks in-depth studies on its effects on natural resource management efficiency (Yin & Li, 2022; Irfan et al., 2022).

2.2. Economic impact of digital governance construction and natural resource efficiency

DGC has emerged as a transformative governance model with profound implications for both micro and macroeconomic impact in regional dimensions. Through the strategic application of digital technologies, DGC enhances governmental governance capacities, improves public health risk management (Lee et al., 2023) and economic growth, and contributes to ecological environmental protection. At the micro-economic level, DGC promotes closer interactions between governments and local citizens through digital platforms, enabling greater transparency, service efficiency and accessibility. For instance, online government services simplify administrative processes, reduce resource wastage and enhance public value creation by fostering trust between governments and citizens (Ma & Zheng, 2019). These digital platforms not only improve public satisfaction but also reduce the government's resource burden by automating services and facilitating more efficient decision-making (Mulyawan, 2024). Furthermore, DGC facilitates collaborative decision-making among businesses and stakeholders, optimising the allocation of limited resources and improving the overall economic efficiency of digital governance. By integrating DGC into regional governance, organisations can make data-driven decisions, enabling more responsive and adaptive governance models.

At the macroeconomic level, DGC has spurred technological advancements and the rise of new business models, fuelling industrial restructuring and economic growth. However, the rapid digitalisation of governance also presents new challenges, particularly cybersecurity risks, such as cyberattacks, data breaches and privacy theft, which threaten both organisational stability and economic resilience (AlGhamdi et al., 2020). To address these risks, DGC enables strategic digital security implementation that protects businesses and governments from such risks, ensuring business continuity and safeguarding economic stability. Additionally, DGC plays a critical role in promoting equal economic development across regions by addressing urban-rural disparities. Leveraging digital platforms, facilitates the equitable flow of information and resources, improving public service delivery and efficiency in rural areas and narrowing regional disparities. By promoting the regional integration of rural areas into the digital economy, DGC not only enhances the quality of public services but also contributes to inclusive and sustainable economic growth.

Natural resources are foundational to socio-economic development, supporting human livelihoods and economic activities. DGC, by leveraging advanced digital technologies, provides cities with critical tools to monitor, manage and optimise resource use. This capacity significantly enhances NRE, reducing wastage and promoting sustainable development (Elbahnasawy, 2021). This supports the following hypothesis:

H1: Digital governance construction has a positive impact on Natural resource efficiency.

2.3. NRE and digital technology

Technological advancement is a key regional driver of enhanced NRE. The development and application of digital technologies reduce resource consumption by enabling more efficient resource management practices (Akram et al., 2021). Digital innovations also facilitate the applications of alternative energy sources and support the transition towards a circular economy, where waste materials are reintegrated into production cycles, thereby maximising resource utilisation and minimising environmental impact (Fan et al., 2025). For example, advancements in energy-efficient technologies and recycling systems substantially enhance the utilisation rate of natural resources while simultaneously mitigating environmental degradation (Ali et al., 2021). DGC enhances the efficiency of resource utilisation by facilitating the exchange of knowledge, technology and innovation across regions. Regions with strong digital infrastructure and a skilled workforce are more likely to achieve digital transformation in advancing sustainable solutions and green transitions (Faggian et al., 2024). The development of regional digital platforms for information sharing and technological collaboration contributes to the growth of the green economy and the adoption of environmentally friendly practices (Fang et al., 2022; Farrukh Shahzad et al., 2025). For example, integrating digital technologies such as artificial intelligence (AI) and big data analytics in natural resource management systems enables governments to optimise resource allocation, minimise waste and improve the sustainability of resource use (Yin & Li, 2022).

In line with DCT, cities with dynamic capabilities are better positioned to adapt and integrate emerging digital technologies, such as big data analytics, AI and the Internet of Things (IoT), into their governance frameworks. These technologies allow for real-time monitoring and precise management of natural resources, all of which significantly improve NRE (Hui et al., 2023). Cities that effectively adopt and implement such digital technologies can expect substantial advancements in resource efficiency. By leveraging digital governance alongside dynamic capabilities, they can address resource management challenges, achieve sustainability goals and foster long-term resilience in resource use. We therefore propose:

H2: Digital governance construction improves natural resource efficiency by enhancing the digital technology level.

2.4. The moderating impact of financial development

Financial development in the local region is another key factor in shaping the relationship between DGC and NRE. Drawing on DCT, cities with well-developed financial systems are better equipped to attract investments in sustainable technologies and regional infrastructure, thereby enhancing their capacity to integrate digital governance into resource management practices (Zhou & Ji, 2025). Advanced financial development fosters an environment in which cities can channel resources toward the adoption of innovative, resource-efficient technologies. This not only supports effective DGC implementation but also facilitates access to capital for projects aimed at improving NRE (Kurniawan et al., 2024). DGC supports financial development by creating a conducive environment for the development of new financial products and services that advance sustainable resource use. Financial institutions, leveraging digital governance advancements, can provide targeted financial products, such as green loans and sustainability-linked investments, to businesses adopting energy-efficient technologies and sustainable practices (Peng, 2024). Such financial support enables businesses to integrate green technologies into their operations, thereby contributing to improving NRE (Irfan et al., 2022). Moreover, by enhancing financial inclusivity and broadening access to investment, DGC can provide the financial foundation necessary for cities to optimise natural resource use. This enhanced access to financial resources ensures that even regions with historically limited financial capital can participate in sustainable development initiatives. We consequently expect the following:

H3. Digital governance construction improves natural resource efficiency by enhancing the financial development level.

2.5. The institutional impact of government participation intensity

Institutional theory further explains how government participation plays a crucial role in shaping the success of DGC initiatives aimed at improving NRE. Institutional theory posits that institutional environments in cities are different in their formal structures, regulations and norms (Xing et al., 2024). In this context, government participation serves as a vital mechanism through which DGC enhances NRE by fostering an environment conducive to sustainable resource management. Through DGC, governments can optimise public service delivery and increase financial expenditures on regional infrastructure and environmental protection, thereby strengthening their capacity for effective resource management (Zhu et al., 2023a). For instance, the local government's financial decentralisation and targeted subsidies for clean energy, recycling and resource-saving technologies encourage innovation and promote the adoption of sustainable practices (Zhu et al., 2023b). Additionally, government investments in regional high-quality infrastructure promote more efficient resource use, reducing waste and contributing to enhanced (Sun et al., 2022).

Active government involvement is particularly critical to ensure the integration of digital technologies into governance systems in alignment with sustainability goals (Choudhuri et al., 2023). When governments intensify their participation in digital governance, they provide the regulatory framework, policy guidance and financial support necessary to ensure that DGC contributes to sustainable resource management. In this regard, increased government participation intensity, facilitated by DGC, strengthens the alignment of governance initiatives with environmental and resource efficiency objectives. Accordingly, we argue:

> H4: Digital governance construction improves natural resource efficiency by increasing government participation intensity.

2.6. The moderating impact of urban ecological resilience

Urban ecological resilience refers to a city's capacity to maintain its functional integrity, structural stability and adaptability in the face of natural and anthropogenic pressures. This concept is central to achieving sustainable urban development, as it enables cities to respond effectively to natural challenges such as natural disasters, environmental degradation and socio-economic instability (Hu & Li, 2024). By enhancing ecological resilience, cities not only improve their disaster preparedness but also optimise the efficiency of natural resource use. This is achieved through the preservation and enhancement of urban ecosystems, including green spaces, rivers and biodiversity-rich regions. These ecosystems are instrumental in sustaining regional ecological balance, and their effective management is increasingly facilitated by DGC, which facilitates the integration of digital technologies into urban governance to optimise resources.

Urban ecological resilience is also expected to influence the relationship between DGC and NRE. Cities with higher ecological resilience demonstrate greater biodiversity, ecosystem stability and adaptive capacity, enabling them to respond more to environmental changes. These regional characteristics allow such cities to more effectively integrate DGC initiatives aimed at improving NRE by optimising the use of digital tools for resource management (Lee et al., 2023). Thus, it is hypothesised that urban ecological resilience positively moderates the relationship between DGC and NRE, as resilient cities can better capitalise on digital governance to enhance sustainability outcomes.

Based on the above, we argue the moderating role of urban ecological resilience and its ability to amplify the positive effects of DGC on NRE. Cities with high levels of ecological resilience are better equipped to incorporate digital governance tools into their environmental management strategies, thereby maximising the positive impacts of DGC on resource efficiency (Lee et al., 2023). These cities, characterised by robust adaptive capacities, are more likely to optimise the use of digital technologies for sustainable resource management. Therefore, we expect:

> H5. The enhancement of urban ecological resilience strengthens the positive effect of digital governance construction on natural resource efficiency.

Together, these hypotheses construct a coherent framework for understanding the mechanisms through which DGC influences NRE. Following this logical line of thought, this study constructs a digital government construction mechanism framework that contains three components at the regional level: digital technology, financial development and government participation intensity, as shown in Figure 1.

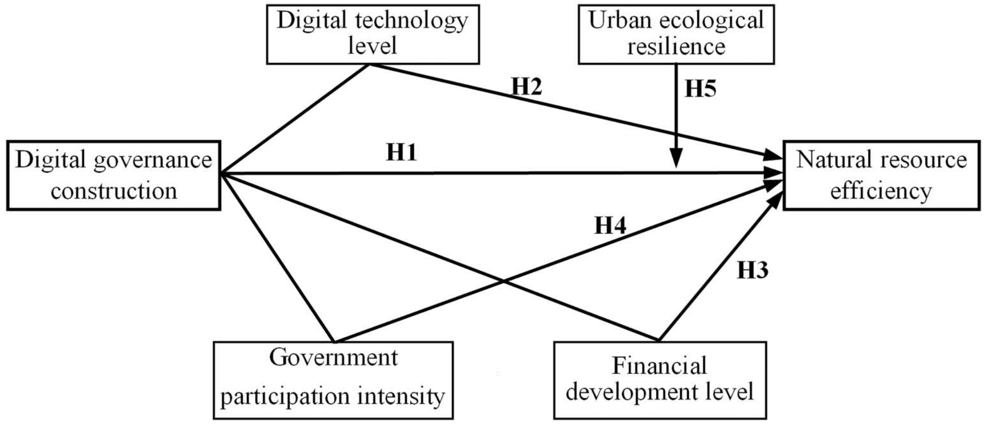

Figure 1. Mechanism diagram. This figure illustrates the mechanism model in which digital governance construction influences natural resource efficiency through multiple pathways, including digital technology level, urban ecological resilience, government participation intensity, and financial development level.

3. Data and methods

3.1. Research methods

3.1.1. SCM

SCM is a quantitative technique designed to evaluate the causal effects of policy interventions. The essence of SCM lies in selecting predictor variables representing the essential determinants of the outcome of interest. These predictor variables are then weighted according to their contribution to the control group, allowing the formation of a 'synthetic control' replicating the pre-intervention characteristics of the treatment group. The post-intervention differences between the synthetic control and the treatment group are then used to infer the causal effect of the policy (Bottmer et al., 2024). This method offers a robust alternative to traditional regression approaches by providing a more precise counterfactual for comparative case studies.

In this paper, we draw on Bottmer and assume that the number of observed districts is $M + 1$ and the sample interval is $[1, T]$. One of the districts becomes a DGC city at T_0, while $1 \le T_0 \le T$ and the other districts serve as a control group. If the act of constructing a digital government has an effect before it is implemented, the paper considers the period in which it has an impact on being T_0. Let Q_{it}^N be the observed economic growth or paradigm shift of the prefecture i in the t period before it becomes a DGC city, and let Q_{it}^I be the observed economic growth or paradigm shift of the prefecture i in the t period after it becomes a DGC city, $i = 1, 2, \cdots, M, M + 1; t = 1, 2, \cdots, T$. The model is written as:

$$Q_{it} = Q_{it}^N + \alpha_{it} D_{it} \tag{1}$$

where D_{it} is a dummy variable for whether to construct a digital government, $D_{it} = \begin{cases} 1, i = 1\, and\, t > T_0 \\ 0, others \end{cases}$.
When $i = 1$ and $t > T_0$, $\alpha_{1t} = Q_{1t} - Q_{1t}^N = Q_1^{IT} - Q_{1t}^N$ is the treatment effect we are exploring. Since Q_1^{IT} is observable when $t > T_0$, Q_{1t}^N is a 'counterfactual' variable that is not directly observable. Therefore, to estimate the treatment effect, Q_{1t}^N should be estimated beforeα_{1t} can be obtained. The factor model is employed in this paper to evaluate the value of Q_{1t}^N:

$$Q_{it}^N = \beta_t + \delta_t X_i + \gamma_t \mu_i + \varepsilon_{it} \tag{2}$$

The β_t in the formula represents a time-fixed effect, X_i is a collective term that is independent of dispositions and does not vary over time, δ_t is its coefficient, $\gamma_t \mu_i$ represents an individual fixed effect and ε_{it} is a random perturbation term.

At the time of estimation Q_{it}^N, the size of the role of different influences on it may be different, therefore, the weight matrix $W = (w_2, \cdots, w_{M+1})'$ is introduced and for any M, $w_2 \ge 0$ and also satisfies y. Therefore, for any x, $x > 1$, and at the same time to satisfy $\sum_{m=2}^{M+1} w_m = 1$. Therefore, Equation (2) can be rewritten as:

$$\sum_{m=2}^{M+1} w_m Q_{mt} = \beta_t + \delta_t \sum_{m=2}^{M+1} w_m X_m + \gamma_t \sum_{m=2}^{M+1} w_m \mu_m + \sum_{m=2}^{M+1} w_m \varepsilon_{mt} \tag{3}$$

Assuming further that the weight matrix $W^* = (w_2^*, \cdots w_{M=1}^*)'$ satisfies $\sum_{m=2}^{M+1} w_m^* X_m = X_1$, for any $t \in [1, T_0]$, $\sum_{m=2}^{M+1} w_m^* Q_{mt} = Q_{1t}$, and $\sum_{i=1}^{T_0} \gamma_t' \gamma_t$ is a non-singular matrix, then combining Equation (2) with Equation (3) yields:

$$Q_{it}^N - \sum_{m=2}^{M+1} w_m^* Q_{mt} = \sum_{m=2}^{M+1} w_m^* \sum_{s=1}^{T_0} \gamma_t (\sum_{s=1}^{T_0} \gamma_n \gamma_n') \gamma_s' (\varepsilon_{ms} - \varepsilon_{1s}) - \sum_{m=2}^{M+1} w_m^* (\varepsilon_{mt} - \varepsilon_{1t}) \tag{4}$$

As the time axis is extended, the value of Equation (4) approaches zero, so $\sum_{m=2}^{M+1} w_m^* Q_{mt}$ can be used as an estimate of Q_{it}^N. So:

$$\bar{\alpha} = Q_{1t} \sum_{m=2}^{M+1} w_m^* Q_{mt} \tag{5}$$

In Equation (5), W^* is an unobservable weight matrix, but approximation can be used to find W^*, which is solved by minimising the distance function.

3.1.2. DID

To assess the impact of DGC on NRE, this study employs the difference-in-differences (DID) method to control for variations in the study population before and after the policy implementation. The DID model is constructed as follows:

$$NRE_{it} = \alpha + \beta_1 \mathrm{DGC}_{it} + \beta_2 X_{it} + \gamma_i + \mu_i + \varepsilon_{it} \tag{6}$$

Among them, i and t represent the period t of city i, respectively. DGC_{it} is a dummy variable for the introduction of digital government policies during the experimental period, taking a value of 1 means that city i has been a pilot city in year t, and taking a value of 0 means that city i is not a pilot city in year t. $control_{it}$ denotes the variables other than the pilot policy that will have an impact on NRE. The introduction of γ_i and μ_i, which respectively represent city-fixed effects and year-fixed effects, allows for a more precise estimation of the influence of temporal and individual characteristics on NRE. X represents a series of control variables, and ε is a random perturbation term. NRE_{it} represents the explanatory variables, denoting NRE of city i in year t.

4. Description of data and variables

4.1. Samples selection and data sources

To align with the Chinese government's national DGC initiatives and enhance provincial DGC capabilities, seven provinces – Guangdong, Jiangsu, Anhui, Guizhou, Fujian, Zhejiang and Guangxi – introduced policies in 2018 aimed at accelerating digital governance. These policies marked the initial phase of DGC implementation within these provinces, as detailed in Table A of Appendix A: data description supplementary documents in the online supplemental data. Table 2 provides the descriptive statistics for the main variables, highlighting key insights into the distribution of natural resource efficiency (NRE). The mean NRE is 0.28, with a standard deviation of 0.266, indicating considerable variability across cities. The minimum observed value of NRE is 0.00371, while the maximum reaches 1.0, reflecting a wide range of resource efficiency outcomes. These results suggest substantial heterogeneity in NRE across cities, which may be attributable to differences in local governance structures, economic development levels and the degree of

Table 2. Descriptive statistics.

Variables	N	Mean	Sd	Min	Max
DGC	3372	0.313	0.464	0	1
NRE	3372	0.280	0.266	0.00371	1
IL	3372	3.795	0.283	2.834	4.315
FDI	3372	0.0278	0.0496	0.000129	0.365
ER	3372	4.487	0.255	3.158	4.605
GI	3372	15.42	1.151	12.88	18.10
RGDP	3372	8.745	4.491	−4.600	22.78
RCL	3372	0.496	0.429	0.0415	3.477
LP	3372	12.80	0.474	11.68	14.08

Digital governance construction (DGC); environmental regulation (ER); opening up level (FDI); financial development level (FDL); government investment (GI); industrialization level (IL); labor productivity (LP); natural resource efficiency (NRE); resident consumption level (RCL); regional economic growth rate (RGDP).

digital governance implementation. This variability underscores the importance of investigating how DGC initiatives influence NRE, as the effects may vary significantly depending on contextual factors.

By identifying these variations, the study sets the stage for a more nuanced exploration of the factors driving NRE, providing a basis for further empirical analysis to examine the impact of DGC policies on resource efficiency across different urban contexts.

In Appendix A: data description supplementary document, in the online supplemental data, we present Table B, the definitions of the variables in the study. Furthermore, we provide a detailed description of explanatory variables, mediating variables and the moderating variable.

5. Empirical analysis

5.1. SCM

5.1.1. Analysis of SCM results

This study applies the extended SCM as introduced by Bottmer et al. (2024) to assess the impact of DGC on NRE. By aggregating data from 88 cities in the experimental group, the study creates a new 'overall pilot city' unit, thus addressing a common limitation of traditional SCM, which is typically constrained to a single experimental unit. The remaining cities are used to form the control group, allowing for a more robust comparative analysis. This method enhances the accuracy of the results by assessing the collective impact across multiple units.

Figure 2 illustrates the trajectories of NRE growth for both the actual and synthetic pilot cities over the period from 2010 to 2021, with the vertical dashed line indicating the year of policy implementation in 2018. Before the implementation of DGC policies, the NRE of the real pilot cities aligns closely with that of the synthetic control group, confirming the validity of the SCM model's pre-treatment fit. However, following the implementation of DGC policies in 2018, a significant divergence is observed: the NRE of the real pilot cities exceeds that of the synthetic control group.

This notable post-policy increase in NRE for real pilot cities suggests that the introduction of DGC policies has a positive effect on improving NRE. The empirical evidence thus supports the hypothesis that DGC enhances the efficiency of resource use in cities where these policies have been implemented. The results underscore the utility of SCM in evaluating policy interventions and highlight the significant role that DGC can play in advancing sustainable resource management.

Additionally, Figure 3 shows the difference in NRE between the actual pilot cities and the synthetic control cities is evident. From 2012 to 2017, the NRE trajectories of the real pilot and synthetic pilot cities remained roughly parallel, with minimal deviation from the zero-value line. This stable pre-intervention trend reinforces the validity of SCM in accurately capturing the baseline conditions.

However, following the implementation of DGC policies in 2018, a discernible and increasing divergence in NRE emerges between the pilot cities and the synthetic control group. This growing disparity suggests that DGC has had a significant positive impact on improving NRE. Furthermore, the continued widening of this difference over time indicates that the effectiveness of DGC in promoting resource efficiency has progressively strengthened. These findings provide robust empirical support for the argument that DGC initiatives contribute to sustained improvements in natural resource efficiency, with their effects amplifying over the long term.

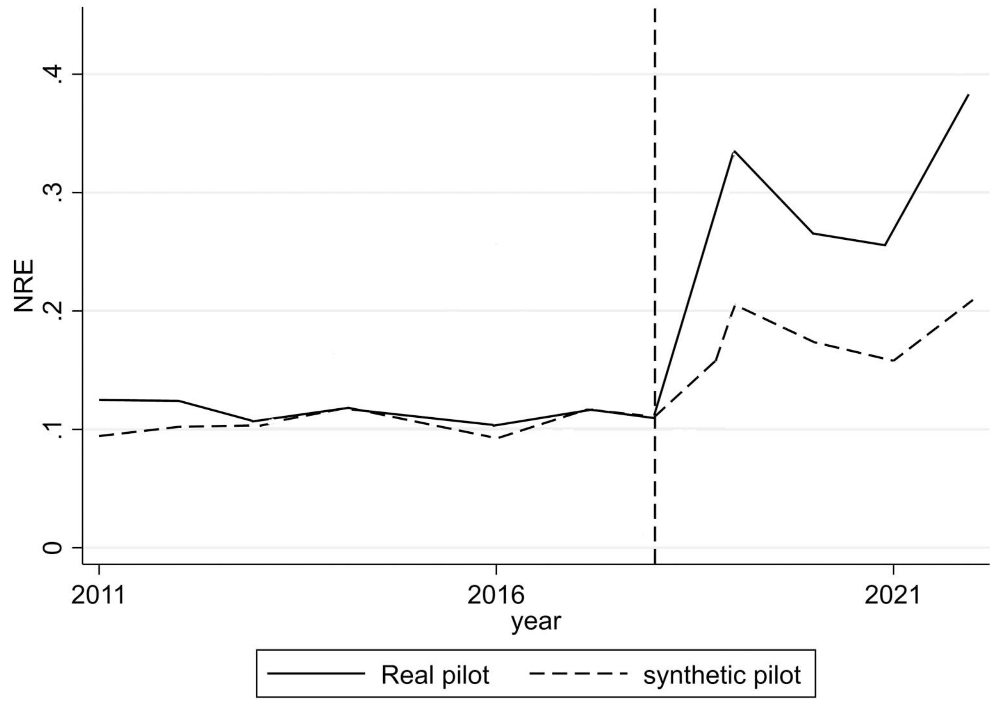

Figure 2. Comparison of NRE between real pilot and synthetic pilot. This figure illustrates the comparison of natural resource efficiency (NRE) trends between the real pilot region and the synthetic control group from 2011 to 2022, highlighting a significant post-intervention improvement in the real pilot following the implementation of digital governance reforms.

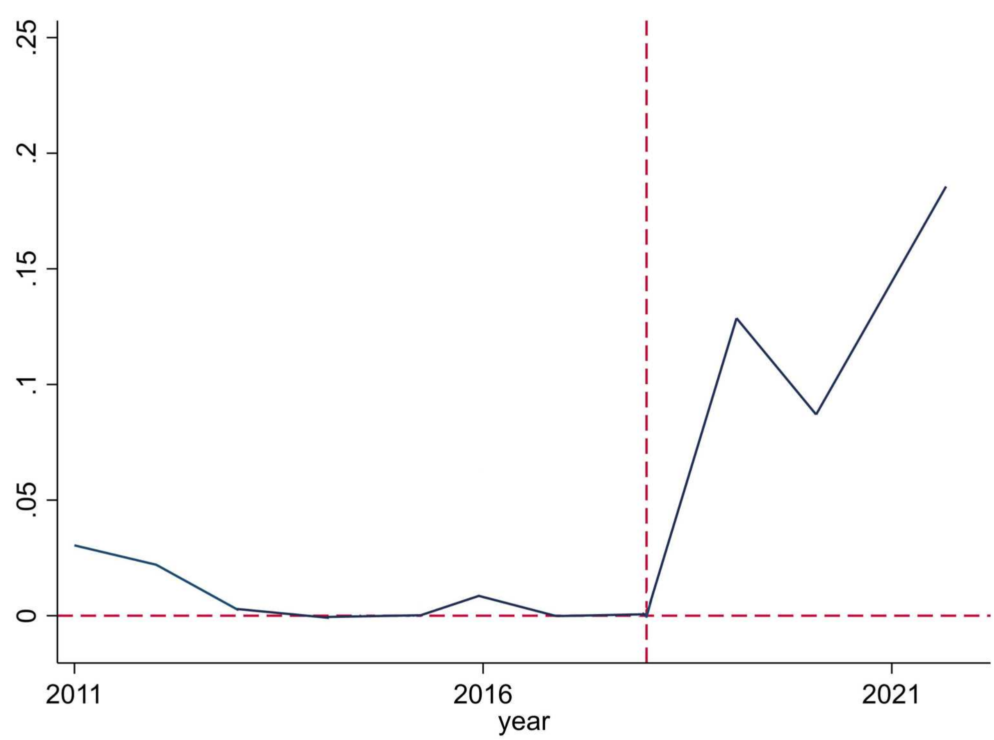

Figure 3. Difference in NRE between real and synthetic pilots. This figure illustrates the annual difference in natural resource efficiency (NRE) between the real pilot and the synthetic control group, showing a significant and sustained positive treatment effect following the implementation of digital governance around 2017.

5.1.2. Sorting test

To further validate the conclusions derived from SCM, this study employs the ranking test proposed by Bottmer et al. (2024). The purpose of this test is to determine whether non-pilot cities, when subjected to the SCM, yield results and probabilities as those observed in the pilot cities. The ranking test assumes that all control group cities initiated DGC policies in 2018 and then applied the same SCM methodology to construct synthetic control units for these non-pilot cities. By comparing the effects observed in the actual pilot cities with those of the hypothetical DGC implementation in the control cities, the test examines whether a significant difference exists between the two scenarios.

If a notable divergence is detected between the real and hypothetical effects, it suggests that DGC has had a tangible impact on the NRE of pilot cities. This approach enhances the robustness of the empirical analysis by ensuring that the observed improvements in NRE are not driven by random fluctuations but are indeed attributable to DGC policies.

In this analysis, the root mean square percentage error (RMSPE) is employed as a key metric to assess the fitness between the real pilot cities and their synthetic counterparts. A larger RMSPE value indicates a poorer fit, signalling that the synthetic control unit does not accurately replicate the trajectory of the real pilot cities before the intervention. To maintain the integrity of the results, cities with RMSPE values exceeding double that of the DGC policy by 2018 are excluded from the analysis. This ensures that only cities with a satisfactory pre-treatment fit are included, thereby increasing the reliability of the policy impact assessment.

$$RMSPE = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(Y_{1t} - \sum_{k=2}^{K+1}\varpi_k Y_{kt})^2} \tag{8}$$

Figure 4 illustrates the trajectory of NRE variation between the cities implementing DGC and their corresponding synthetic control group. Prior to 2018, the variation in RMSPE between the pilot cities and the synthetic control group remained relatively stable and showed no significant deviation compared to other

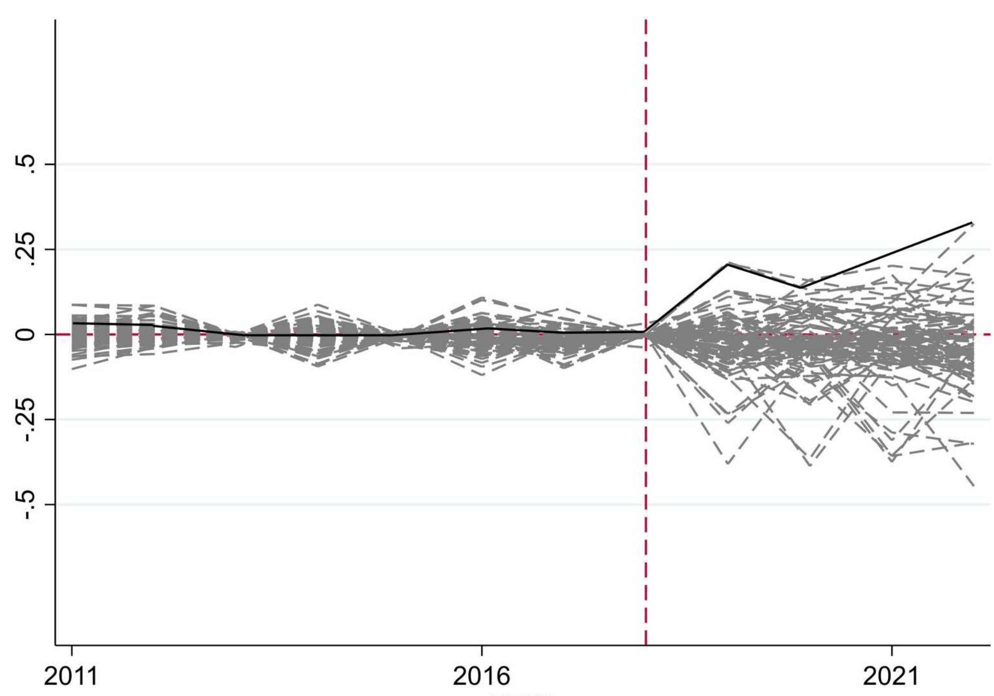

Figure 4. Sorting test. This figure presents the results of the placebo test (or sorting test), where each dashed line represents a synthetic control for a placebo unit. The solid black line denotes the actual treated unit. Following the intervention in 2017, the real pilot exhibits a significantly larger positive effect on natural resource efficiency (NRE) compared to most placebo units, indicating that the observed treatment effect is unlikely to be due to chance.

municipalities. However, after the introduction of DGC policies in 2018, a clear divergence emerges, with the gap progressively widening over time.

The NRE curve for the real pilot cities consistently positions itself above the majority of the RMSPE distribution, indicating that the NRE performance in the pilot cities significantly outperforms that of the synthetic control group post-DGC implementation. This pronounced divergence provides strong empirical evidence that DGC policies have effectively contributed to the enhancement of NRE. The elevation of the real pilot's curve, relative to the synthetic control group, underscores the positive and sustained impact of DGC initiatives on resource efficiency outcomes.

5.2. Difference-in difference test

5.2.1. Benchmark regression results

The empirical evidence derived from DID model specified in Equation (6) is presented in Table 3. The positive and statistically significant coefficient of the interaction term treat*post suggests that cities implementing DGC policies have experienced improvements in NRE.

Model (1) reports the baseline regression results, which exclude control variables and city or time fixed effects. Despite the absence of these controls, the treat*post term is statistically significant, providing preliminary evidence that DGC positively influences NRE. In Model (2), fixed effects for both cities and years are introduced to control for time-invariant characteristics and temporal shocks, while control variables remain excluded. The positive and significant coefficient for treat*post in Model (2) further confirms the robustness of the DGC's impact on NRE.

Models (3) and (4) introduce control variables to account for additional factors that may influence NRE. In Model (3), control variables are included, but city and year fixed effects are not. In Model (4), both control variables and fixed effects are incorporated to provide a more comprehensive analysis. The estimated coefficient for treat*post in Model (4) is 0.064 and remains statistically significant at the 1% level. These results strongly support H1, which posits that DGC significantly enhances NRE in cities that adopt these policies.

Appendix B: data analysis supplementary documents, in the online supplemental data, show the robustness tests, including parallel trend test, placebo test, propensity score matching-difference-in-differences and synthetic difference-in-differences.

Table 3. Benchmark regression results.

	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
Treat*post	0.076***	0.076***	0.064***	0.064***
	(3.72)	(3.01)	(3.35)	(2.65)
IL			0.043***	0.204***
			(2.81)	(5.71)
FDI			0.177***	0.179
			(4.05)	(0.82)
ER			−0.009	0.017
			(−0.58)	(1.03)
GI			0.038***	−0.064***
			(9.47)	(−4.63)
RGDP			0.001	−0.005***
			(0.87)	(−4.07)
RCL			−0.020***	−0.049**
			(−3.09)	(−2.33)
LP			0.129***	0.053***
			(12.63)	(2.88)
_cons	0.239***	0.234***	−2.102***	−0.264
	(36.48)	(58.02)	(−15.44)	(−1.06)
City FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES
N	3372	3372	3372	3372
R^2	0.442	0.547	0.454	0.431

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, similarly hereafter.
Environmental regulation (ER); opening up level (FDI); government investment (GI); industrialization level (IL); labor productivity (LP); resident consumption level (RCL); regional economic growth rate (RGDP).

5.2.2. Heterogeneous analysis

In this study, we have conducted five heterogeneous analyses: (1) heterogeneity test based on digitisation level, (2) heterogeneity test based on industrial structure, (3) heterogeneity test based on government transparency, (4) heterogeneity test based on urban resource endowment and (5) heterogeneity test based on market access, available in Appendix B in the online supplemental data.

5.3. Analysis of moderating effects

5.3.1. Model specification

The preceding analysis demonstrates that DGC positively influences NRE. To further investigate whether this relationship is moderated by urban ecological resilience, this study incorporates urban ecological resilience as a moderating variable into the DID framework. Specifically, the interaction term between urban ecological resilience and the DID variables is included to assess the potential moderating effect. The following model is constructed to test the hypothesis:

$$NRE_{it} = \alpha + \beta_1 Treat_{it} \times Post_{it} + \beta_2 U\text{er} + \beta_3 \times Treat_{it} \times Post_{it} \times Uer + \beta_4 X_{it} + \gamma_i + \mu_t + \varepsilon_{it} \tag{10}$$

In the model, $U\text{er}$ represents the level of urban ecological resilience, while the other variables retain the same definitions as in Equation (6). To assess the moderating effect of urban ecological resilience, the signs and statistical significance of the interaction terms are examined. These are then compared with the coefficients of the Treat × post term from the baseline regression results (Column 4). This comparison helps determine whether urban ecological resilience plays a moderating role in the process of enhancing NRE through DGC.

5.3.2. Effect analysis

The regression coefficient for the main effect, as shown in Column (5) of Table 3, is 0.082 and is statistically significant at the 5% level. Analysing the moderating effects, the interaction term between urban ecological resilience, digital governance and the time dummy variable yields a coefficient of 0.290, indicating that urban ecological resilience strengthens the positive relationship between DGC and NRE. This result confirms H5, suggesting that in cities with high levels of ecological resilience, DGC has an even more pronounced facilitating effect on NRE.

The underlying rationale is that urban ecological resilience reflects a city's ability to manage and utilise resources effectively. Higher resilience implies greater attention to environmental sustainability and the efficient use of natural resources, as well as reflecting local resource abundance and government attitudes, which send important signals to the market. In cities with high ecological resilience, governments can better adjust resource utilisation promptly. Consequently, when DGC is expanded in these cities, the adoption of new technologies and methods is more readily embraced, facilitating both the conservation and efficient use of natural resources.

Moreover, enterprises are more likely to pursue green transformations in environments that highlight resource conservation (Zhu et al., 2023b). These transformations reduce pollution, promote circular economy practices and lay a solid foundation for improving NRE. The combination of robust ecological resilience and DGC thus creates a synergistic effect that not only maintains the supply of natural resources but also promotes their sustainable and efficient utilisation.

5.4. Mechanism analysis

5.4.1. Model setting

Constructing a mediated effects model to test the mechanisms by which DGC affects NRE:

$$Inter = \varpi + \varpi_1 did_{it} + \varpi_2 X_{it} + \gamma_i + \mu_t + \varepsilon_{it} \tag{11}$$

$$NRE_{it} = \upsilon + \upsilon_1 did_{it} + \upsilon_2 X_{it} + \upsilon_3 I\text{nter} + \gamma_i + \mu_t + \varepsilon_{it} \tag{12}$$

where *Inter* is the mediating variable and the other variables correspond to those mentioned in the previous section. ϖ_1 represents the influence of DGC on the mediating variable, while υ_3 signifies the impact of

Table 4. The estimation results of action mechanism test.

Variables	DTL (1)	NRE (2)	FDL (3)	NRE (4)	GPI (5)	NRE (6)
DGC	0.327***		0.038**		0.153***	
	(4.73)		(2.24)		(7.51)	
DTL		0.072***				
		(7.02)				
FDL				0.006		
				(0.76)		
GPI						0.121***
						(6.69)
Control	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	3372	3372	3372	3372	3372	3372
R^2	0.403	0.092	0.142	0.538	0.264	0.497

Digital governance construction (DGC); digital technology level (DTL); financial development level (FDL); government participation intensity (GPI).

the mediating variable on NRE. The application of stepwise regression suggests the existence of a mediating effect when both variables demonstrate significance.

5.4.2. Mechanism test

The regression results presented in Table 4 indicate that the coefficients for the policy variables related to the digital technology level (DTL) as a mediating factor are significantly positive. This suggests that DTL plays a crucial mediating role in the relationship between DGC and NRE. The implementation of DGC policies encourages cities to prioritise the integration of information systems and networks, thus providing abundant data resources and promoting the application and diffusion of digital technologies. The development of digital technologies introduces new opportunities for enhancing NRE by enabling more efficient resource management and optimisation. This result confirms H2, suggesting that digital governance construction improves natural resource efficiency by enhancing the digital technology level.

Additionally, DGC policies facilitate the creation of new financial products and services that promote financial innovation. This financial innovation can generate increased outputs, which may have implications for NRE. The regression results in Columns (3) and (4) of Table 4 show that the coefficients for the impact of policy variables on the financial development level (FDL) are also significantly positive at the 5% level, indicating that DGC policies contribute to the enhancement of FDL. However, despite this improvement in financial development, there is no substantial effect on NRE, implying that FDL does not serve as a significant mediating variable in the relationship between DGC and NRE. This result confirms H3, suggesting that digital governance construction improves natural resource efficiency by enhancing the financial development level.

Moreover, the coefficients for the policy variables related to government investment (GI) are consistently positive and significant, indicating that higher government involvement positively influences NRE. Government intervention, particularly through research investment and increased fiscal expenditure, has a meaningful mediating effect on the relationship between DGC and NRE. DGC initiatives often require both time and financial support, leading to increases in government spending. This increased fiscal expenditure enables more active government involvement in resource allocation, which in turn impacts NRE. Furthermore, financial investments in digital government are often directed toward upgrading digital infrastructure and advancing digital technologies through research and development. The utilisation of vast amounts of data and digital technology ultimately contributes to the improvement of NRE. This result confirms H4, suggesting that digital governance construction improves natural resource efficiency by increasing government participation intensity.

6. Discussion

6.1. Research findings

The growing implementation of DGC has reshaped how regions pursue the SDGs, especially concerning natural resource efficiency (NRE). While existing literature has acknowledged the potential of digital governance to improve transparency and service delivery (Shiyi & Dengke, 2018; Ma & Zheng, 2019), its empirical impact on environmental and resource outcomes remains underexplored. Our study bridges this gap by using longitudinal data from 281 Chinese cities (2010–2021) and employing a robust empirical framework, including SCM, DID, PSM-DID and Synthetic Difference-in-Differences (SDID), to evaluate the causal impact of DGC on NRE.

Our results demonstrate that DGC policies significantly enhance NRE in pilot cities, with the effect being more pronounced in cities characterised by higher levels of digitisation, simpler industrial structures, greater financial transparency and stronger market access. This regional heterogeneity resonates with prior findings on the uneven spatial diffusion of innovation and the territorial capacity framework in multi-dimensional regionalism (MDR) debates, reinforcing the notion that institutional and technological readiness are critical enablers of digital environmental governance. Our findings empirically validate that DGC fosters more efficient natural resources use primarily through advancements in digital technology, financial development and proactive government involvement, all of which align with the ecological modernisation literature (Shahbaz et al., 2022).

In addition, this study finds that urban ecological resilience plays a moderating role in this mechanism, amplifying the effects of DGC on NRE. This finding enriches existing discourse on regional adaptive capacity by showing how ecological infrastructure and disaster resilience function as institutional multipliers, not only buffering environmental shocks but also enhancing the governance efficacy of digital policy tools. It reflects an emerging scholarly consensus that place-based resilience and digitally mediated interventions are mutually reinforcing in sustainable regional development.

Lastly, we extend these findings to broader governance frameworks. While generalisation requires caution, particularly in regions with weaker digital or institutional infrastructures, the identified mechanisms regarding digital adoption, financial maturity and ecological resilience provide a transferable foundation for analysing the potential of DGC in other national and regional contexts. By linking these mechanisms back to the theoretical constructs in the MDR and governance literature, our results offer not just empirical insights but also conceptual refinement.

6.2. Theoretical contributions

Our study contributes to the regional studies literature with novel nuances of digital governance and resource management by introducing a new perspective on how DGC can enhance NRE. First, we advance prior research on digital governance by demonstrating how digital government initiatives can improve environmental outcomes, linking governance with ecological sustainability (Shiyi & Dengke, 2018). The study sheds light on how digital technology, government financial participation and urban ecological resilience interact to improve NRE, thus adding a novel dimension to the literature on governance and environmental policy.

Furthermore, the study contributes to extending the resource dependence theory by showing that resource-based cities benefit disproportionately from digital governance due to their dependence on natural resources. Specifically, while framing resource optimisation as a function of governance quality, this research shows how DGC reduces resource inefficiency and promotes sustainable practices in resource-based cities.

In addition, considering regional heterogeneity, we present new empirical evidence that contributes to offering the theoretical framework of ecological modernisation by shedding light on the role of government intervention and technological innovation in driving environmental improvements. DGC, by fostering the adoption of advanced digital technologies and green financing mechanisms, aligns with the ecological modernisation paradigm that posits technological progress as a key driver of ecological sustainability (Hao et al., 2024; Shahbaz et al., 2022). As such, our study reveals how DGC policies facilitate the transition to a green economy by promoting cleaner production methods and resource efficiency.

6.3. Practical implications

The study finds that DGC has a significant and positive impact on NRE, with varying effects across different contexts. Regions with high levels of digitisation, cities with more transparent government financial practices, resource-dependent cities and those with greater market access experience more substantial improvements in NRE due to DGC policies. The research also indicates that urban ecological resilience amplifies the impact of DGC on NRE, further reinforcing the importance of local ecological and governance factors.

The findings of this study provide several practical implications for policymakers and stakeholders aiming to enhance NRE through digital governance. First, policymakers should tailor DGC initiatives to regional characteristics, focusing on advanced digital infrastructure in highly digitised cities while building foundational technological capacity in less digitised areas. Strengthening urban ecological resilience is also crucial, as it plays a moderating role in the success of DGC. This can be achieved through investments in sustainable urban planning, environmental protection and resource conservation, ensuring cities are better prepared to adopt DGC policies. Additionally, promoting financial innovation and green financing is vital. Governments should encourage financial products, such as green bonds and loans, to fund clean technologies and sustainable practices, leading to better NRE outcomes. Government participation in sustainable development is another key area. Increased financial investment in digital infrastructure, clean technologies and research and development (R&D), along with incentives for enterprises to adopt environmentally friendly practices, will further support the transition to a green economy. Cross-regional collaboration should also be facilitated, allowing regions with varying levels of digital development to share resources and experiences, promoting equitable and efficient resource use. Finally, resource-dependent cities should be prioritised for digital transformations because DGC has a more substantial impact in these areas. By encouraging the adoption of digital technologies, these cities can transition towards cleaner production methods and improved NRE.

6.4. Limitations and future research

Despite its theoretical and empirical novelty, this study has several limitations that warrant attention in future research. First, although our focus on the longitudinal data from specific periods and 88 regions in China offers insightful findings on the role of DGC in enhancing NRE, this finding may limit the generalisability of the findings across countries. Moreover, our data collection involves the secondary data of government reports investigating policy effects. We found that the accessibility and completeness of available government reports in China may introduce biases. Additionally, the study focuses primarily on cities, neglecting the impact of DGC on rural areas, where digital infrastructure and resource management may differ significantly. Future research should aim to expand the geographical and sectoral scope, as well as explore longer time frames to validate and enrich these findings. It would be valuable for future studies to extend this study by exploring the long-term impacts of DGC on NRE, focusing on rural areas and diverse sectors, such as agriculture and mining. Additionally, further research could investigate the role of public participation and corporate responsibility in amplifying the effects of DGC on NRE. Cross-country comparisons would also be beneficial for understanding the broader implications of DGC policies on global resource management and environmental sustainability. Future research on addressing these research conversations will potentially make critical scholarship contributions.

7. Conclusion

This study demonstrates that digital governance construction (DGC) can significantly enhance natural resource efficiency (NRE), especially in urban regions characterised by high digitisation, transparent governance and active market participation. Yet, the impact of DGC is far from uniform – its efficacy is deeply conditioned by territorial capacity, ecological resilience and institutional readiness. These findings affirm that digital governance is not a one-size-fits-all solution; rather, it must be contextually embedded and regionally adaptive.

Our research findings directly contribute to long-standing epistemological and academic debates in regional science, particularly concerning the role of institutions and technology in mediating spatial inequality and ecological transitions. By foregrounding how DGC reshapes the governance – resource nexus across diverse urban settings, we extend MDR frameworks with new empirical insight into how digital infrastructures, fiscal instruments and environmental resilience interact in a spatially differentiated manner. Furthermore, the study advances the ecological modernisation scholarship by providing evidence that digital governance is not only a technological upgrade but also a restructuring force that reconfigures how regions conceptualise and operationalise sustainability. Last, but not least, this study offers practical recommendations to policymakers. Promoting DGC must go beyond infrastructure deployment. It is important to strengthen region-specific capacities, integrating environmental intelligence into public decision-making and enabling interjurisdictional collaboration. In resource-dependent or institutionally fragile regions, foundational investment in digital capacity and governance trust is a precondition for sustainable outcomes. By centring the analysis on regional variation, this research consequently argues that digital governance, if thoughtfully designed and critically implemented, can serve as a transformative pathway toward inclusive, efficient and place-sensitive resource management.

Data availability statement

The data that support the findings of this study are available from the first author, upon reasonable request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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