

Does climate change respond to government digitization? Empirical evidence from greenhouse gas emissions

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Abstract

Purpose – Against the backdrop of global digitization and accelerating climate change, this study aims to examine how government digitization affects greenhouse gas (GHG) emissions, highlighting its environmental tradeoffs under different economic and political conditions.

Design/methodology/approach – Using panel data from 130 countries over the period 2002–2021, a fixed-effect model examines the effect of government digitization on GHG emissions. After robustness checks, three fixed-effect models with interaction terms explore the underlying mechanisms. Group tests then investigate the moderating roles of energy security risk, economic policy uncertainty and ruling party ideology. Finally, quantile regression reveals how this effect varies by national emission levels.

Findings – Government digitization significantly increases GHG emissions, with benchmark estimation showing a specific magnitude: each 0.1-unit increase in government digitization is associated with an average increase of 0.0023 Mt CO₂e in GHG emissions. This emission-enhancing effect operates through rising electric power consumption, improved total factor productivity and promoted business digitization. This effect is further moderated by energy security risk, economic policy uncertainty and ruling party ideology. Quantile regression reveals that this effect is statistically insignificant in low-emission countries, but becomes increasingly associated with higher GHG emissions as national emission levels rise.

Originality/value – This study advances the literature by challenging the prevailing belief that government digitization is inherently emission-reducing. It reveals potential emission-enhancing mechanisms and investigates how diverse economic and political factors shape these outcomes, thereby offering a more nuanced understanding and providing theoretical and practical insights for the design of environmentally sustainable digital governance strategies.

Keywords Government digitization, Climate change, Greenhouse gas emissions, Energy security risk, Economic policy uncertainty, Ruling party ideology

Paper type Research paper

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1. Introduction

Amid ongoing social and economic development, the intensification of human activities, particularly the large-scale combustion of fossil fuels and alterations in land use, has led to a sustained increase in atmospheric greenhouse gas (GHG) concentrations. This accumulation has disrupted the earth's radiative balance and become a primary driver of global climate change, manifesting in long-term temperature rise and increasingly erratic climate patterns (Bhatti *et al.*, 2024). The consequences of climate change are multifaceted and profound, including the escalation of extreme weather events, rising sea levels and biodiversity loss. These climate-induced disruptions not only threaten natural ecosystems but also compromise food security, damage critical infrastructure and strain global supply chains, thereby exposing economies to heightened risks and volatility (Yan *et al.*, 2023). Furthermore, governments are compelled to divert significant fiscal resources toward climate mitigation and adaptation efforts, which adds pressure to public finances. As such, addressing the root causes and impacts of climate change, most notably the persistent growth in GHG emissions, has become an urgent global challenge (Pavel *et al.*, 2024).

As asserted by the United Nations Environment Programme, the rapid development of digital technologies plays a critical role in tackling global environmental sustainability (Wang *et al.*, 2024). In response to the escalating climate crisis, digitization has been widely recognized as a transformative force in environmental governance (Bonsignore, 2024). It is often viewed as an important facilitator of green finance flows into environmentally responsible sectors, thereby enhancing environmental sustainability (Ye *et al.*, 2024). A growing body of empirical literature supports the view that digitization contributes to reducing GHG emissions, a conclusion confirmed in studies on China (He *et al.*, 2025; Zhao *et al.*, 2023), OECD economies (Alvi *et al.*, 2025), the European Union (Dimian *et al.*, 2025; Kwilinski *et al.*, 2023) and the G7 economies (Chen *et al.*, 2023).

While the emission-mitigating role of digitization is widely acknowledged, it is essential to highlight the pivotal role that governments play in steering digitization. Acting as both regulators and public service providers, governments are instrumental in promoting digital initiatives and realizing their potential effects on GHG emissions. In this context, a growing body of research has shifted focus from broad digitization to the more specific domain of government digitization, and several recent studies explicitly emphasize this directional shift (Feng *et al.*, 2024; Li *et al.*, 2025; Wang *et al.*, 2024; Yi, 2025; Zhang *et al.*, 2025). Notably, these studies diverge in their conclusions regarding government digitization's emission impact: most argue it curbs carbon emissions, whereas Li *et al.* (2025) emphasized carbon emissions from digital government operations and empirically revealed an inverted U-shaped effect.

A brief review of the existing literature reveals that most studies tend to overemphasize the environmental benefits of government digitization while neglecting the GHG emissions associated with its own operation. Although Li *et al.* (2025) provided a valuable supplement to this line of research, certain limitations in their research design could weaken the validity of their findings. First, Li *et al.* (2025) did not use a U-test to verify the existence of an inverted U-shaped relationship; instead, they inferred its presence solely based on the statistically significant negative coefficient of the squared term of government digitization. This approach is insufficiently rigorous, as convex and monotonic effects could also erroneously exhibit a U-shape with an extremum (Lind and Mehlum, 2010). Second, the digital government data released by the United Nations reflect the situation of the previous year rather than the current year. Li *et al.* (2025) failed to account for this temporal characteristic, and the resulting time mismatch could introduce bias into their findings. Moreover, while Li *et al.* (2025) discussed the emission-increase effect of government

digitization at the theoretical level, they provided no direct empirical evidence to support the underlying mechanism. As such, this study empirically revisits the impact of government digitization on GHG emissions, considering both its positive and negative effects.

In addition to empirically examining the impact of government digitization on GHG emissions and uncovering mechanisms that have not been sufficiently explored in the existing literature, this paper contributes to the literature in several other ways. First, various economic and political variables are incorporated into the analytical framework to explore their moderating roles. Specifically, energy security risk could influence the logic of resource allocation associated with digital government initiatives by shaping regulatory priorities between environmental and energy considerations; policy uncertainty could alter the way government digitization affects emissions by disrupting policy coherence and market expectations; and ruling party ideology could affect the environmental consequences of government digitization by determining government priorities. Existing studies have yet to clarify how these three contextual factors shape the nexus between government digitization and GHG emissions, making it necessary to investigate their moderating effects to refine the theoretical framework. Moreover, the principle of diminishing marginal effect suggests potential heterogeneity in the impact of government digitization across different distributional stages, a critical dimension that has been largely overlooked in prior empirical investigations. To address this, this paper uses quantile regression analysis. Together, the moderation analysis and quantile regression provide a more nuanced understanding of how and under what conditions government digitization affects environmental outcomes, thereby offering more targeted and effective policy implications.

The possible marginal contributions of this study are as follows. First, unlike the prevailing view in the literature that emphasizes the emission-reducing effect of government digitization, this paper empirically confirms that government digitization can intensify GHG emissions. This finding challenges the unidirectional perception of its environmental impact, provides a new empirical perspective for understanding its complex role in GHG governance and offers evidence for reassessing the environmental costs and tradeoffs of government digitization. Second, by incorporating energy security risk, policy uncertainty and ruling party ideology into the analytical framework, this study addresses the insufficient attention to moderating factors in existing research and enriches the analytical dimensions of the intersection between digital governance and environmental economics. Finally, the heterogeneous effects of government digitization across different GHG emission levels revealed in this study not only provide new empirical testing of the applicability of the diminishing marginal effect theory in the field of environmental governance but also offer practical guidance for enhancing the precision of environmental policy design based on this finding.

Section 2 develops the research hypotheses. Section 3 describes the data and methodology used. Section 4 reports and interprets the empirical findings. Section 5 summarizes the main conclusions, outlines relevant policy implications and acknowledges the study's limitations.

2. Theoretical analysis and hypothesis development

2.1 *The impact of government digitization on GHG emissions*

Government digitization is typically accompanied by the rapid expansion of information infrastructure, such as the large-scale deployment of data centers, cloud computing platforms and smart terminal devices (Li *et al.*, 2025). The operation of these facilities requires substantial electricity consumption. Given that the energy mix remains heavily reliant on fossil fuels, the resulting increase in energy demand inevitably leads to higher GHG

emissions (Ikevuje *et al.*, 2024). As such, without a green development pathway, the process of government digitization will inevitably exert negative pressure on environmental sustainability. Based on this, we propose *H1a*:

H1a. Government digitization could increase GHG emissions by raising electric power consumption.

Government digitization could influence GHG emissions by affecting total factor productivity (TFP). First, digital governance can reduce information asymmetry and administrative barriers, thereby optimizing the allocation efficiency of public resources and directly improving TFP in the public sector (Ding *et al.*, 2025a). Specifically, cross-departmental data sharing on digital government platforms helps streamline redundant procedures in policy implementation, thereby reducing energy consumption and GHG emissions of the administrative system itself. At the same time, by lowering institutional transaction costs for enterprises (Mohamed *et al.*, 2023), it indirectly enhances the production efficiency of market entities and promotes the reallocation of production factors from high-emission industries to low-emission sectors. In addition, digital-enabled collaborative governance can amplify the synergy between TFP improvement and emission reduction. Specifically, government-led cross-regional and cross-sector digital platforms can integrate data related to low-emission industrial transitions, promoting the efficient flow and allocation of production factors within circular economy systems. On one hand, this efficient allocation directly enhances resource use efficiency, thereby driving the improvement of TFP; on the other hand, precise matching and recycling of production factors help reduce logistical redundancy and avoidable emissions in production processes. However, it is worth noting that the economic scale expansion brought by TFP improvement could also lead to emission rebounds. As such, the effect of government digitization on GHG emissions via TFP remains ambiguous. Based on this, we propose *H1b*:

H1b. Government digitization could influence GHG emissions via TFP, though the effect's direction is unclear.

Business digitization could serve as a transmission channel through which government digitization affects GHG emissions. On one hand, government actions have a guiding role. The digitization of high-frequency public services creates a strong demonstration effect that stimulates businesses to undertake similar transformations. Within industrial clusters, this imitation effect generates a diffusion mechanism, forming a transmission chain from governments to leading businesses and eventually to small and medium-sized businesses, thereby promoting widespread adoption of digitization across the business sector. On the other hand, governments can reduce businesses' costs of data collection and processing by establishing standardized data interfaces and shared platforms. In addition, the provision of modular digital tools can shorten the business digitization cycle and lower initial investment costs, further enhancing businesses' willingness to pursue digitization. The emission effects of business digitization are twofold. On the mitigation side, business digitization can reduce emissions by improving energy efficiency, enhancing financial performance and fostering green innovation (Gao *et al.*, 2023). On the amplification side, the energy consumption of digital devices is non-negligible. Moreover, increasing investment in digitization by businesses can crowd out input in environmentally friendly production and alter production modes to accommodate large-scale output, thereby increasing emissions (Yang *et al.*, 2024). In sum, government digitization can promote business digitization,

while the emission impacts of business digitization exhibit a dual nature. Based on this, we propose *H1c*:

H1c. Government digitization could influence GHG emissions via business digitization, though the effect's direction is unclear.

The analysis of *H1a* through *H1c* reveals that government digitization could affect GHG emissions through multiple channels. Among these pathways, only the energy consumption effect identified in *H1a* has a clearly defined direction of influence, while the impacts of the other two mechanisms remain theoretically ambiguous. Accordingly, we propose an overarching *H1*:

H1. Government digitization could influence GHG emissions, though the effect's direction is unclear.

2.2 The impact of three moderators on the relationship between government digitization and GHG emissions

Energy security risk could influence the environmental effects of digital government initiatives by shaping resource allocation. In countries with lower energy security risk, stable energy supply alleviates these governments' pressure to ensure energy availability, thereby allowing digital regulatory efforts to focus more on improving environmental quality. Governments in such contexts are more likely to prioritize digital resources toward green governance tools, fostering a virtuous interaction between digital regulation and emission reduction incentives. This, in turn, facilitates a synergistic alignment between digital government development and climate mitigation goal. In contrast, in countries facing higher energy security risk, regulatory priorities are often skewed toward ensuring energy accessibility (Cong *et al.*, 2025). Governments in these contexts tend to concentrate digital resources on strengthening the capacity for energy supply assurance. Such a resource allocation preference could crowd out investment in digital infrastructure needed for environmental regulation, leading to underdevelopment in this area. Consequently, the effectiveness of environmental enforcement is weakened, and the effect of government digitization in increasing GHG emissions tends to be amplified. Based on this, we propose *H2*:

H2. Energy security risk could moderate the impact of government digitization on GHG emissions.

In countries with low economic policy uncertainty, policy directions are clearer and institutional arrangements tend to be more coherent. Under such conditions, market participants are more likely to make long-term green transition decisions based on stable expectations. This institutional environment provides critical support for the effective application of government digitization in the environmental domain. On one hand, coherent policy frameworks help clarify environmental regulatory targets, enabling governments to leverage digital technologies for real-time emission monitoring and data sharing, thereby enhancing the precision and transparency of environmental supervision. On the other hand, stable expectations make firms more willing to comply with digital regulatory initiatives, which lowers the resistance to their implementation. In short, in such countries, government digitization is more readily translated into concrete environmental governance capacity, thus significantly curbing GHG emissions. By contrast, in countries with high economic policy uncertainty, policy coherence is often disrupted, leading to unstable market expectations

(Fu *et al.*, 2022). To hedge against policy volatility, firms tend to shorten investment horizons and focus on short-term returns, thereby weakening their motivation for green transition and environmental compliance. At the same time, frequent policy shifts and inefficiencies in regulatory coordination hinder the stable integration of digital tools into the environmental regulatory framework. As a result, in such countries, government digitization is less likely to evolve into effective environmental governance and its emission reduction effect tends to be substantially diminished. Based on this, we propose *H3*:

H3. Economic policy uncertainty could moderate the impact of government digitization on GHG emissions.

A government's attention to different sectors can be influenced by the ideology of the ruling party (Wen *et al.*, 2022). As such, ruling party ideology could affect government's attention to the environmental sector, thereby moderating the relationship between government digitization and GHG emissions. Compared with right-wing parties, left-wing parties are more willing to prioritize environmental protection (Neumayer, 2004). This is further supported by Matuszczak *et al.* (2020), who found that members and supporters of left-wing parties are mostly environmentalists. Driven by such ideological preferences, governments led by left-wing parties are more likely to prioritize the application of digital technologies in the field of environmental governance. Accordingly, government digitization tends to play a substantive role in environmental governance, thereby effectively curbing GHG emissions. In contrast, right-wing parties place more emphasis on market freedom and capital efficiency, and their policy priorities tend to tilt toward industrial expansion and deregulation of enterprises (Jäger, 2017). Under this policy orientation, government digitization could be used to simplify approval procedures for resource-heavy sectors and reduce environmental compliance costs, turning digital tools into catalysts for the development of energy-intensive industries, and ultimately exacerbating GHG emissions. By comparison, centrist parties tend to adopt a more pragmatic stance, seeking a balance between environmental objectives and economic concerns. In this context, government digitization is less likely to be systematically directed toward strengthening environmental governance, as is often the case under left-leaning governments, nor is it inclined to foster resource-intensive industries in the manner of right-leaning governments. Instead, government digitization's impact on GHG emissions could be more neutral, reflecting the centrist pursuit of compromise between environmental protection and economic growth. Based on this, we propose *H4*:

H4. Ruling party ideology could moderate the impact of government digitization on GHG emissions.

2.3 Heterogeneity in the impact of government digitization across different distributional stages

The impact of government digitization on GHG emissions could vary significantly across countries with different emission levels. In low-emission countries, the environmental role of government digitization tends to be relatively limited, primarily reflected in two types of contexts. First, in countries that have not yet completed industrialization, weak economic foundations and a lack of capital constrain the development of digital infrastructure and human capital, thereby restricting the effectiveness of government digitization in environmental governance. Second, in countries that have already undergone green transitions and possess a high level of government digitization, although their governance capacity is relatively strong, the

small pollution base and limited room for further improvement mean that government digitization plays a more auxiliary role, with low marginal effects.

In countries with moderate emission levels, the influence of government digitization could be more pronounced. These countries are typically undergoing rapid industrialization and urbanization, characterized by dynamic economic activity and strong energy demand. Government digitization can enhance administrative efficiency and resource allocation, thereby improving enterprise productivity (Ding *et al.*, 2025b). This improvement in productivity, in turn, intensifies energy consumption and GHG emissions.

By contrast, in high-emission countries, the emission-promoting effect of government digitization tends to weaken. On one hand, the expansion of emission-intensive industries faces diminishing marginal returns, reducing incentives for governments to further support their growth. On the other hand, due to their prolonged industrialization processes, these countries have developed relatively mature digital governance systems, possessing a solid technical foundation for digital regulation while also facing greater pressure in environmental governance. As a result, government digitization is more likely to be leveraged to enhance the enforcement of environmental policies and strengthen monitoring of emission sources, thereby mitigating its contribution to emission increases. Based on this, we propose *H5*:

- H5.* The impact of government digitization on GHG emissions varies across emission levels, with limited impact in low-emission countries, the strongest positive impact in medium-emission countries, and weaker positive or even negative impact in high-emission countries.

3. Data and methodology

3.1 Data

Based on data availability, this study uses data from 130 countries [1] over the period 2002–2021 to empirically examine the impact of government digitization on GHG emissions. The dependent variable, total GHG emissions (*TGHGE*), is obtained from the World Development Indicators (WDI) database. Government digitization (*GD*), the core explanatory variable, refers to the structured integration of advanced information and communication technologies into public sector operations, with the goal of enhancing administrative efficiency and improving the accessibility and quality of digital public services (Verma and Dawar, 2019). To quantify *GD*, we adopt the online service index published by the United Nations, which systematically assesses the extent and performance of digital government services (Castro and Lopes, 2022) [2]. Following Ding *et al.* (2023), this research introduces several control variables, including gross domestic product (*GDP*) and its squared term (*GDP_squared*), total population (*TP*), urbanization rate (*UR*), the share of value added by the service industry in GDP (*SI*), net inflows of foreign direct investment as a share of GDP (*FDI*) and the share of fossil fuel energy consumption in total energy use (*FFEC*). The control variable data are obtained from the WDI database. Table 1 summarizes the descriptive statistics for all the above variables. Notably, the variables named *TGHGE*, *GDP* and *TP* are transformed using natural logarithms in the regression analysis to mitigate possible heteroscedasticity. Accordingly, the descriptive statistics for these three variables are based on their natural logarithmic values.

3.2 Methodology

3.2.1 Benchmark regression and robustness checks. To test *H1*, we will use a fixed-effect model for the benchmark regression, as outlined in equation (1). In this equation, *Z* denotes

the control variables, while fixed effects for countries and years are captured by μ_i and ν_t , respectively. The parameters of interest are α_0 , α_1 and β , with ε_{it} representing the error term.

$$\text{Ln}(TGHGE_{it}) = \alpha_0 + \alpha_1 GD_{it} + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{1}$$

To ensure the reliability of the benchmark finding, we will conduct robustness tests. First, a placebo test will be conducted. Following the approach of [Cornaggia and Li \(2019\)](#), we remove the original *GD* values and randomly reallocate these values across the sample before re-estimating [equation \(1\)](#).

To alleviate potential endogeneity, we will use system GMM estimation and two-stage least squares (2SLS) estimation. To conduct a system GMM estimation, as shown in [equation \(2\)](#), we added the lag term of the dependent variable ($TGHGE_{i,t-1}$) as an instrumental variable into [equation \(1\)](#). As for 2SLS estimation, following [Ding et al. \(2025a\)](#), *GD* is treated as an endogenous variable and the average *GD* of other countries in the same region [\[3\]](#), and year is selected as the instrumental variable (IV):

$$\text{Ln}(TGHGE_{it}) = \alpha_0 + \alpha_1 \text{Ln}(TGHGE_{i,t-1}) + \alpha_2 GD_{it} + \beta Z_{it} + \varepsilon_{it} \tag{2}$$

3.2.2 Mechanism analysis. To conduct mechanism testing, we follow the empirical strategy used by [Wen et al. \(2021\)](#), which entails incorporating two additional explanatory variables into [equation \(1\)](#). Specifically, to investigate the channel proposed in *H1a*, namely, that government digitization influences GHG emissions via electric power consumption (*EPC*), we introduce both *EPC* and its interaction term with *GD* ($GD \times EPC$) into the regression model, resulting in [equation \(3\)](#). The *EPC* data are from the WDI database.

To test the mechanisms proposed in *H1b* and *H1c*, we replace *EPC* in [equation \(3\)](#) with TFP (*TFP*) and business digitization (*BD*), respectively, as shown in [equations \(4\)](#) and [\(5\)](#). The *TFP* data are sourced from the Penn World Table. As for *BD*, we select five indicators from the United Nations Conference on Trade and Development Digital Economy Database: proportion of businesses placing orders over the Internet (PBPOI), proportion of businesses receiving orders over the Internet (PBROI), proportion of businesses using computers (PBUC), proportion of businesses using the Internet (PBUI) and proportion of businesses with a web presence (PBWP), as its proxies. Principal component analysis (PCA) is then applied to these five indicators to construct the *BD* index [\[4\]](#). Although this approach could not capture the full complexity of business digitization, it remains appropriate given the constraints of data availability. Specifically, PBUC and PBUI represent the digital infrastructure dimension, reflecting firms' basic capacity to access digital tools and serving

Table 1. Descriptive statistics of full sample

Category	Variable name	Measurement	Mean	SD	Min.	Max.
Dependent variable	<i>TGHGE</i>	Mt CO ₂ e	5.544	0.844	0.000	9.545
Independent variable	<i>GD</i>	Index	0.509	0.260	0.000	1.000
Control variables	<i>GDP</i>	Constant 2015 US\$	25.080	1.910	19.785	30.672
	<i>TP</i>	People	16.301	1.636	11.320	21.070
	<i>UR</i>	Proportion	0.614	0.216	0.142	1.000
	<i>SI</i>	Proportion	0.545	0.110	0.097	0.941
	<i>FDI</i>	Proportion	0.067	0.280	-0.575	4.500
	<i>FFEC</i>	Proportion	0.659	0.286	0.000	1.000

as a prerequisite for subsequent digital activities. PBWP captures firms' ability to establish an online presence and display information, which is a core feature of digital existence. PBPOI and PBROI focus on the digitization of business processes, directly reflecting the extent to which digital technologies have penetrated transaction activities:

$$\ln(TGHGE_{it}) = \alpha_0 + \alpha_1 GD_{it} + \alpha_2 EPC_{it} + \alpha_3 (GD_{it} \times EPC_{it}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

$$\ln(TGHGE_{it}) = \alpha_0 + \alpha_1 GD_{it} + \alpha_2 TFP_{it} + \alpha_3 (GD_{it} \times TFP_{it}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (4)$$

$$\ln(TGHGE_{it}) = \alpha_0 + \alpha_1 GD_{it} + \alpha_2 BD_{it} + \alpha_3 (GD_{it} \times BD_{it}) + \beta Z_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (5)$$

3.2.3 Group tests. To examine *H2* and *H3*, which pertain to the moderating roles of energy security risk (*ESR*) and economic policy uncertainty (*EPU*), we adopt the approach used by [Jadiyappa et al. \(2021\)](#). Concretely, the full sample is split into four subgroups based on the median values of the two moderators [5], and [equation \(1\)](#) is estimated independently for each subgroup. Following [Cong et al. \(2025\)](#), we used the national energy security risk index from the Global Energy Institute as *ESR*'s proxy. Notably, a higher score on this index reflects a weaker state of energy security. In line with [Ryu and Yu \(2022\)](#), the economic policy uncertainty index is selected as *EPU*'s proxy. Because the index is reported at a monthly frequency, we take its annual average to more accurately capture the overall policy uncertainty. As *EPU* data are only available for 22 economies, the scope of this analysis is accordingly limited.

To examine *H4*, which concerns the moderating effect of ruling party ideology (*RPI*), the full sample is divided into left-wing, right-wing and centrist governments, and [equation \(1\)](#) is estimated separately for each subgroup. Information on *RPI* can be obtained from the Database of Political Institutions.

3.2.4 Quantile regression. To test *H5*, which posits that the effect of government digitization on GHG emissions varies across emission levels, we apply quantile regression. This method provides a more refined understanding of distributional heterogeneity that cannot be captured by mean-based estimates ([Islam et al., 2025](#)). We estimate [equation \(1\)](#) at the 0.1, 0.25, 0.5, 0.75 and 0.9 quantiles of the emission distribution.

4. Empirical findings and discussion

4.1 Results of benchmark estimation and robustness checks

Column 1 of [Table 2](#) reports the benchmark regression results. The coefficient of *GD* is statistically significant at the 1% level, indicating that government digitization has a significant impact on GHG emissions, thereby confirming *H1* [6]. Moreover, the positive sign of the coefficient (0.023) suggests that government digitization exacerbates GHG emissions. This finding challenges the conventional view of government digitization as a driver of green transformation and, to some extent, corroborates the dominant role of the electric power consumption effect proposed in *H1a*. Specifically, in the absence of a well-developed green development pathway, the expansion of information infrastructure driven by government digitization could increase electric power consumption and thus lead to higher GHG emissions. Although government digitization could also reduce emissions indirectly by enhancing *TFP* (*H1b*) and promoting business digitization (*H1c*), as discussed in subsection 2.1, both channels could theoretically also increase emissions. Even if the mechanisms proposed in *H1b* and *H1c* indeed contribute to emission reduction in practice, the significantly

positive coefficient of *GD* suggests that their potential mitigating effects are not sufficient to offset the emission increases driven by higher electric power consumption in this context. Overall, this result highlights the complexity of the environmental consequences of government digitization and underscores the need to integrate green development strategies into digital governance reform to ensure alignment between technological advancement and environmental sustainability.

Regarding the control variables, two results warrant particular attention. First, the coefficient of *GDP_squared* is positive and statistically significant, which contradicts the inverted U-shaped relationship predicted by the Environmental Kuznets Curve (EKC). A similar empirical pattern was reported by Wang and Kim (2024) in a US context, who attribute this result to increases in emissions from the transportation sector, strong electricity demand during cold winter seasons, the reversal of eco-friendly energy policies and the reshoring of manufacturing activities. Second, although conventional wisdom suggests that urbanization tends to increase environmental pressure through greater transportation demand and energy consumption (Zhou et al., 2019), *UR* is negatively signed and statistically significant, indicating that urbanization reduces GHG emissions. This counterintuitive finding could be explained by the efficiency-enhancing effects of urbanization, such as intensified infrastructure use and improved resource allocation, both of which contribute to lower emission intensity (Pata, 2018).

The results of the placebo test are reported in Column 2 of Table 2. The coefficient of *GD* is statistically insignificant, ruling out the possibility that the benchmark finding is a placebo. Moreover, after replacing the estimation method with system GMM (Column 3, Table 2) and 2SLS (Table 3), *GD* consistently obtains a statistically significant positive coefficient. These results collectively confirm the robustness of the benchmark finding.

Table 2. Benchmark estimation and robustness checks (placebo test and system GMM)

Variable	Fixed effect I	Placebo test II	System GMM III
GD	0.023*** (2.83)	−0.001 (−0.10)	0.014** (2.07)
GDP	−0.940*** (−6.52)	−0.936*** (−6.47)	−0.811*** (−3.04)
GDP_squared	0.021*** (7.31)	0.021*** (7.23)	0.017*** (4.09)
TP	0.137*** (7.45)	0.135*** (7.34)	0.011*** (3.22)
UR	−0.119* (−1.76)	−0.148** (−2.24)	0.013 (0.05)
SI	−0.152** (−2.50)	−0.158*** (−2.60)	−0.069* (−1.73)
FDI	0.137* (1.84)	0.138* (1.86)	0.010 (0.12)
FFEC	0.447*** (12.60)	0.453*** (12.80)	−0.146 (−0.96)
Constant	13.335*** (7.54)	13.394*** (7.56)	10.149*** (3.34)
Lagged dep. var			0.946*** (13.73)
R-squared	0.407	0.332	
Observations	1,256	1,256	810
Country FE	YES	YES	
Year FE	YES	YES	
Sargan test			0.402
AR(1)			0.000
AR(2)			0.397

Note(s): *t*-Statistics are in parenthesis; ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively

Table 3. Robustness check (2SLS)

Variable	I	II
IV	0.526*** (5.29)	
GD		0.120** (2.15)
GDP	0.246** (2.50)	−2.569*** (−19.20)
GDP_squared	−0.004** (−2.19)	0.054*** (20.35)
TP	0.015** (2.55)	0.195*** (18.04)
UR	0.047 (1.44)	0.061 (1.23)
SI	0.124** (2.26)	−0.415*** (−5.26)
FDI	0.170 (1.15)	−0.019 (−0.08)
FFEC	0.026 (1.48)	0.396*** (13.30)
Observations	1,256	1,256
Country FE	Yes	Yes
Year FE	Yes	Yes
F statistic	20.07	

Note(s): *t*-Statistics are in parenthesis; ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively

4.2 Results of mechanism tests

Table 4 presents the mechanism analysis results. The *EPC* in Column 1, the *TFP* in Column 3, and the *BD* in Column 5 all yielded statistically significant positive coefficients, suggesting that these factors contribute to higher GHG emissions. Furthermore, the interaction terms $GD \times EPC$ in Column 2, $GD \times TFP$ in Column 4 and $GD \times BD$ in Column 6 are also significantly positive, indicating that government digitization increases GHG emissions by raising electric power consumption, enhancing TFP and promoting business digitization, thereby supporting *H1a*, *H1b* and *H1c* [7].

Further discussion is warranted regarding *H1b* and *H1c*. Both TFP improvement and business digitization can theoretically have dual effects on GHG emissions: on one hand, they could lower emissions by enhancing efficiency and fostering green innovation; on the other hand, they could raise emissions through the energy demands of digital infrastructure and the expansion of production capacity. Our findings show that the latter effect currently dominates, as both higher TFP and deeper business digitization are associated with increased GHG emissions. This suggests that, at the present stage, advances in productivity and digital adoption are more closely tied to output expansion than to emission reduction, highlighting the need for policies that guide TFP growth and digitization toward greener development pathways. This policy orientation is consistent with the insights from Riaz *et al.* (2025), who warned that without aligning digital advancement with green energy systems, the association between digitization and output expansion will overshadow emission reduction goals. Similarly, Ridwan *et al.* (2025) emphasized that circular economy practices are essential to counteract the emission-intensive effects of productivity growth, making the integration of circular principles into industrial systems a crucial step for achieving low-carbon development.

However, the robustness and generalizability of the finding on the business digitization mechanism encounter two limitations. First, due to limitations in *BD* data availability, the test of *H1c* relies on only 110 observations, with missing data undermining statistical reliability. Second, the sample composition further constrains generalizability: most of these observations are from high-income economies, where mature digital infrastructure could

Table 4. Mechanism tests

Variable	I	Electric power consumption II	III	Total factor productivity IV	V	Business digitization VI
GD		-0.028 (-0.81)		0.097 (1.04)		0.014 (0.46)
GDP	-1.006*** (-7.11)	-0.984*** (-6.43)	-0.386** (-2.20)	-0.397** (-2.25)	0.631 (0.66)	0.744 (0.74)
GDP_squared	0.022*** (7.67)	0.021*** (6.99)	0.009*** (2.72)	0.010*** (2.81)	-0.010 (-0.55)	-0.013 (-0.63)
TP	0.069*** (3.52)	0.071*** (3.59)	0.107*** (4.75)	0.102*** (4.31)	0.243 (1.44)	0.248 (1.45)
UR	-0.287*** (-4.28)	-0.253*** (-3.69)	-0.151* (-1.91)	-0.137* (-1.71)	-0.510 (-0.94)	-0.399 (-0.67)
SI	-0.201*** (-3.35)	-0.197*** (-3.27)	-0.148** (-2.37)	-0.150** (-2.38)	-0.117 (-0.87)	-0.124 (-0.89)
FDI	0.116 (1.58)	0.115 (1.57)	0.196** (2.49)	0.199*** (2.52)	-0.059 (-0.44)	-0.041 (-0.29)
FFEC	0.352*** (9.57)	0.338*** (9.12)	0.360*** (9.07)	0.354*** (8.87)	0.240** (2.27)	0.242** (2.21)
EPC	0.060*** (7.93)	-0.042*** (-5.00)				
GD × EPC		0.009*** (3.54)				
TFP			0.003** (2.13)	-0.040* (-1.88)		
GD × TFP				0.007** (2.06)		
BD					0.203** (2.46)	-0.196** (-2.39)
GD × BD						0.195*** (2.23)
Constant	14.467*** (8.33)	14.023*** (7.46)	7.377*** (3.41)	7.495*** (3.44)	-7.439 (-0.56)	-9.107 (-0.66)
R-squared	0.438	0.442	0.308	0.311	0.288	0.293
Observations	1,231	1,231	871	871	110	110
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

Note(s): *t*-Statistics are in parenthesis; ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively

amplify the emission effects of *BD*, thereby biasing the overall regression results. Hence, the applicability of this conclusion to low-income economies could be substantially weakened.

4.3 Results of group tests

Table 5 presents the estimation results for seven subsamples. In countries characterized by higher energy security risk (Column 2), higher economic policy uncertainty (Column 4) and right-wing governments (Column 6), *GD* exhibits a significantly positive coefficient at least at the 5% level, indicating that government digitization intensifies GHG emissions. In contrast, in countries with lower energy security risk (Column 1), lower economic policy uncertainty (Column 3) and left-wing governments (Column 5), government digitization significantly reduces GHG emissions. In addition, Column 7 reports the results for centrist governments. The coefficient of *GD* is positive and statistically significant at the 10% level (0.015), but its magnitude is smaller than that of right-wing governments (0.039, Column 6). This aligns with the theoretical expectation in *H4*, with centrist parties prioritizing a balance between environmental protection and economic concerns. Consequently, government digitization under centrist governance neither amplifies GHG emissions as strongly as under right-wing rule nor curbs GHG emissions as under left-wing rule, resulting in a weaker emission-enhancing effect. These findings confirm the moderating roles of energy security risk [8], economic policy uncertainty and ruling party ideology, thus supporting *H2*, *H3* and *H4*.

4.4 Results of quantile regression

Table 6 reports the quantile regression results. At the 0.1 quantile, the coefficient of *GD* is statistically insignificant. In contrast, at the remaining four quantiles, the coefficients are positive and statistically significant, with their magnitudes gradually increasing across higher quantiles. This suggests that in countries with lower levels of GHG emissions, the impact of government digitization on emissions is negligible; however, as emission levels rise, the positive effect of government digitization on GHG emissions becomes increasingly pronounced. This finding is inconsistent with the expectation of *H5*, which anticipated a weaker positive or even negative relationship in high-emission countries.

Nonetheless, this deviation from the hypothesis could be explainable. *H5* rests on the assumption that high-emission countries have largely completed the phase in which government digitization enhances the efficiency of traditional industries and are now reallocating digital resources toward green governance. In practice, however, this assumption faces two important challenges. First, in most high-emission countries, government digitization is still in its developmental phase (Profirou et al., 2024); the empowerment it provides to improve the efficiency of traditional industries has not yet reached the stage of diminishing marginal returns, meaning that ongoing digitization efforts can continue to stimulate industrial capacity expansion. Second, compared to the pressure for economic growth, environmental constraints in these countries tend to be relatively weak (Ding et al., 2023), making it difficult for digital resources to shift toward green governance in the short term. Crucially, the timing of diminishing marginal effects varies substantially across countries, development stages and research domains, making its specific occurrence empirically uncertain. In the context of this study, we have not found clear evidence that the impact of government digitization on GHG emissions has begun to exhibit diminishing marginal effects.

4.5 Comparison with previous studies

The empirical results of this study present notable deviations from the mainstream literature and offer meaningful extensions to the current understanding of the environmental

Table 5. Group tests

Variable	I	Energy security risk II	III	Economic policy uncertainty IV	V	Ruling party ideology VI	VII
GD	-0.011** (-2.06)	0.069*** (3.34)	-0.012** (-2.38)	0.034** (2.47)	-0.009*** (-2.80)	0.039** (2.37)	0.015* (1.83)
GDP	-0.133 (-0.24)	-1.563*** (-5.09)	0.810*** (4.11)	0.503*** (7.28)	-0.099 (-0.19)	0.343 (0.98)	-1.104 (-0.81)
GDP_squared	0.004 (0.34)	0.034*** (5.34)	-0.201*** (-4.02)	-0.198*** (-7.20)	0.003 (0.32)	-0.005 (-0.67)	0.024 (0.89)
TP	0.049 (0.88)	0.225*** (5.04)	0.107 (1.10)	-0.164 (-0.98)	0.272*** (3.31)	0.040 (0.66)	0.053* (1.75)
UR	0.180 (1.38)	0.219 (1.10)	0.329 (1.46)	-0.370 (-1.01)	-0.033 (-0.16)	-0.070 (-0.44)	-1.371 (-1.15)
SI	-0.068 (-0.54)	0.000 (0.00)	-1.220*** (-4.66)	0.515** (2.26)	-0.220 (-1.25)	-0.133 (-1.11)	-0.139 (-0.47)
FDI	0.422*** (2.98)	0.053 (0.35)	0.106 (0.57)	-1.184*** (-2.97)	0.538*** (2.85)	0.229* (1.85)	0.239 (1.05)
FFEC	0.690*** (9.76)	0.803*** (7.67)	0.663*** (4.62)	0.385* (1.69)	0.105 (1.12)	0.380*** (5.79)	0.202 (1.34)
Constant	5.390 (0.76)	19.072*** (4.67)	11.141*** (4.07)	13.324*** (7.32)	1.511 (0.24)	-0.992 (-0.22)	19.704 (1.09)
R-squared	0.372	0.573	0.773	0.737	0.339	0.384	0.453
Observations	315	315	98	99	281	256	83
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note(s): *t*-Statistics are in parenthesis; ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively

Table 6. Quantile regression

Variable	QR_10 I	QR_25 II	QR_50 III	QR_75 IV	QR_90 V
GD	-0.008 (-0.86)	0.010*** (2.63)	0.029*** (2.88)	0.037*** (2.96)	0.041*** (2.47)
GDP	-3.484*** (-22.29)	-3.754*** (-44.58)	-2.997*** (-72.98)	-2.124*** (-26.39)	-0.070 (-0.17)
GDP_squared	0.071*** (22.88)	0.077*** (44.86)	0.063*** (79.42)	0.046*** (27.64)	0.006 (0.76)
TP	0.185*** (33.08)	0.208*** (18.36)	0.177*** (12.62)	0.150*** (16.99)	0.136*** (15.80)
UR	-0.039 (-1.16)	-0.019 (-0.70)	0.104*** (3.19)	-0.015 (-0.50)	-0.043 (-1.02)
SI	-0.014 (-0.25)	-0.102** (-2.04)	-0.473*** (-5.50)	-0.695*** (-10.50)	-0.397*** (-2.01)
FDI	-0.257 (-1.57)	-0.284 (-1.23)	-0.319 (-1.30)	-0.081 (-0.49)	0.165 (0.38)
FFEC	0.597*** (32.95)	0.519*** (23.11)	0.220*** (5.31)	0.232*** (8.84)	0.173*** (4.66)
Country FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

Note(s): *t*-Statistics are in parenthesis; ***, **, * and * denote statistical significance at the 1, 5 and 10% levels, respectively

consequences of government digitization. While a large body of existing research tends to emphasize the emission-reducing potential of government digitization (e.g. [Feng et al., 2024](#); [Wang et al., 2024](#); [Yi, 2025](#); [Zhang et al., 2025](#)), our findings suggest that government digitization can, in fact, intensify GHG emissions under certain conditions. This challenges the prevailing belief that digital governance is inherently aligned with environmental sustainability and calls for a more nuanced assessment of its environmental implications. Moreover, our results diverge from those of [Li et al. \(2025\)](#), who argued for an inverted U-shaped relationship between government digitization and carbon emissions. Although their study highlights the dual environmental effects of digital governance, it lacks rigorous empirical testing for the turning point and does not account for the temporal lag in *GD* data. In contrast, our quantile regression analysis does not support the existence of a U-shaped pattern; rather, it shows that the emission-promoting effect of government digitization becomes more pronounced at higher levels of emissions, implying that digitization in high-emission countries has yet to be redirected toward green governance. This finding is further reinforced by our group-testing analysis, which reveals that energy security risk, policy uncertainty and ruling party ideology, substantially moderate the impact of government digitization on GHG emissions. These results help explain the heterogeneity in previous empirical findings and underscore the importance of accounting for institutional and contextual factors. In sum, this study enriches the existing literature by shifting the focus from a predominantly optimistic view to a more balanced understanding of the complex and conditional effects of government digitization on climate outcomes.

5. Conclusion

5.1 Summary of findings

Based on panel data from 130 countries over the period 2002–2021, this study conducts a series of empirical analyses and draws the following conclusions:

- Government digitization significantly increases GHG emissions; more specifically, it contributes to higher emissions by increasing electric power consumption, enhancing TFP and promoting business digitization.
- The impact of government digitization on GHG emissions is moderated by energy security risk, economic policy uncertainty and ruling party ideology. Specifically, in countries facing severe energy security risk, experiencing elevated policy uncertainty, or governed by right-wing parties, government digitization significantly increases GHG emissions; in contrast, under conditions of low energy security risk, stable policy environment or left-wing governance, it significantly reduces emissions; for countries governed by centrist parties, government digitization also exerts an emission-increasing effect, though the effect is weaker than under right-wing governments.
- The effect of government digitization on GHG emissions varies by countries' GHG emission levels, with the effect being insignificant in low-emission countries but increasingly contributing to higher emissions as emission levels rise.

5.2 Policy implications

The empirical findings of this study provide important insights for policy formulation aimed at aligning government digitization with climate mitigation goals. First, given the demonstrated positive association between government digitization and GHG emissions, as well as the identification of electric power consumption as a key transmission mechanism, it

is imperative to improve the energy structure underpinning digital infrastructure. Governments should embed green standards throughout the entire lifecycle of government digitization, particularly by prioritizing the use of clean energy to power data centers and communication networks, so as to reduce the GHG footprint and mitigate the environmental consequences of digitization. Second, the finding that government digitization increases GHG emissions through business digitization underscores the importance of policy efforts that steer private-sector digitization in an environmentally responsible direction. Measures such as green tax incentives could encourage the adoption of low-emission digital technologies and discourage digital investments that lead to excessive GHG emissions. Third, the results regarding energy security risk, economic policy uncertainty and ruling party ideology highlight the critical role of national conditions in shaping the environmental consequences of government digitization. In countries facing energy supply instability or frequent policy shifts, governments should strengthen the resilience of their energy systems and enhance policy consistency to prevent digital government initiatives from exacerbating GHG emissions. In addition, fostering political consensus on the environmental objectives of digital government initiatives, regardless of political ideology, could help ensure long-term commitment to environmental sustainability in the context of digital government. Finally, because the emission effects of government digitization vary across countries with different emission levels, digital governance reforms should adopt a differentiated approach. In high-emission countries, efforts should focus not only on enhancing digital tools for environmental monitoring and enforcement, but also on applying digital technologies to improve energy efficiency and reduce overall GHG emissions in emission-intensive sectors. In contrast, in countries with lower emission levels and relatively underdeveloped digital infrastructure, priority should be given to building environmentally sustainable digital capacity from the outset, ensuring that the expansion of digital government does not lead to unintended environmental burdens.

5.3 Limitations and suggestions for future research

Despite the rigorous efforts devoted to ensuring the accuracy of this study, certain unresolved limitations persist. First, due to data availability constraints, this study used online service index as *GD*'s proxy, which primarily captures digitization of public services rather than the broader digital transformation of the public sector. If more comprehensive indicators become available in the future, researchers could extend the analysis to encompass wider dimensions of digital governance and thereby achieve a more comprehensive assessment of government digitalization's environmental consequences. Second, although we used 2SLS estimation to mitigate potential endogeneity, the validity of the exclusion restriction remains debatable because regional adoption initiatives, such as the European Green Deal, could be correlated with unobserved shocks that also influence GHG emissions. Future research could incorporate falsification tests to further strengthen causal identification.

Data availability

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

Notes

- [1.] The list of the 130 countries is displayed in [Appendix List A1](#).

- [2.] Because the United Nations does not release the online service index annually, and the data published in a given year actually correspond to the previous year, this study in effect covers the years 2002, 2003, 2004, 2007, 2009, 2011, 2013, 2015, 2017, 2019 and 2021.
- [3.] Regional classifications follow the [World Bank \(2022\)](#), which divides countries into seven groups: East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, North America, South Asia and sub-Saharan Africa.
- [4.] Due to space constraints, the empirical results related to the PCA process are not reported in this paper but are available upon request from the corresponding author.
- [5.] Taking *ESR* as an example, countries with values below its median are classified as lower energy security risk countries, whereas those with values equal to or above the median are classified as higher energy security risk countries. The same classification method is applied to *EPU*.
- [6.] To test for a potential nonlinear effect, we included a squared term of *GD* in the regression; its coefficient was not statistically significant. Results are not reported here due to space constraints but are available from the corresponding author upon request.
- [7.] While some countries rely on fossil energy as the main source in their electricity supply and others on renewable energy, this paper does not distinguish this structural difference. To test whether the mechanism proposed in *H1a*, by which government digitization affects GHG emissions through the electricity consumption channel, is driven by fossil energy-dominated power grids, we incorporated the interaction term of government digitization and the share of renewable electricity output in total electricity output (*REOshare*), i.e. $GD \times REOshare$, into the regression. The results indicate that this interaction term yields a significantly negative coefficient at the 5% level, which confirms that the mechanism proposed in *H1a* is indeed driven by fossil energy-dominated power grids. Readers interested in these regression results can request them from the corresponding author.
- [8.] To verify the robustness on the moderating role of energy security risk, we replaced *ESR*'s proxy with the energy security score from the World Energy Council's Energy Trilemma Index and still obtained a consistent finding. Readers interested in these regression results can request them from the corresponding author.

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Appendix

List A1. Sample countries

Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Cabo Verde, Cambodia, Cameroon, Canada, Chad, Chile, Colombia, Comoros, Costa Rica, Croatia, Cyprus, Denmark, Dominican Republic, Ecuador, El Salvador, Equatorial Guinea, Estonia, Eswatini, Ethiopia, Fiji, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Lesotho, Lithuania, Luxembourg, Madagascar, Malaysia, Malta, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Niger, North

Macedonia, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Rwanda, Samoa, Saudi Arabia, Senegal, Seychelles, Singapore, Slovenia, Solomon Islands, South Africa, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Thailand, Timor-Leste, Togo, Tonga, Tunisia, Turkmenistan, Uganda, Ukraine, United Arab Emirates, UK, USA, Uruguay, Uzbekistan, Vanuatu, Viet Nam, Zambia, Zimbabwe.

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