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The contingent role of state capacity on the impact of e-government on environmental sustainability in developing countries

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E-government is a prominent approach in environmental sustainability as it brings various arrangements that allow for the mitigation of greenhouse gas emissions. The article explores two main objectives. Firstly, the direct impact of e-government on ecological sustainability and secondly, whether e-government enhances environmental sustainability indirectly by improving state capacity. By understanding this nexus, we believe that states in LDCs will seek to explore the maximum potential benefits of ICTs in government operations to establish a more responsive, open, and people-oriented government. The paper utilizes a balanced macro-panel sample of 45 United Nations classified least developed countries from 2003 to 2022. To ensure the reliability of empirical findings, three econometric methods—system generalized methods of moments (GMM), instrumental variable GMM (IV-GMM), and bootstrap ordinary least squares (BOLS) are employed. The results of the entire sample model reveal several key findings. These findings are that e-government development has a direct and positive impact on environmental sustainability, secondly state capacity negatively influences ecological sustainability, and lastly e-government development indirectly affects environmental sustainability by enhancing state capacity. Additionally, intriguing sub-sample findings for least developed countries in Africa and Asia are observed, with notable lessons from the latter, where environmental performance is improving at the expense of a high volume of carbon emissions. However, these overall findings underscore the importance of considering how governments can address environmental sustainability requirements by managing e-government programs and enacting responsible ICT-enabled transformations.

KEYWORDS
environmental sustainability, LDCs, ICTs, e-government, state capacity

1 Introduction

Though defined differently by different scholars, electronic government (e-government) entails an orchestration of efforts to deliver government services to citizens through information and communication technologies (ICTs), departing from traditional brick-and-mortar methods (McNabb, 2017; United Nations, 2016). E-government is often used interchangeably with e-governance, but the latter refers to the use of ICT in enhancing the range and quality of information and services to the public, in a more transformative manner to increase citizen or constituency engagement with their government (Bannister and Connolly, 2012; Marcovecchio et al., 2019; Setiya et al., 2021; Mutiarin et al., 2024).

Meronen's (2017) survey of Finnish public and private sector organizations reveals that a large proportion of respondents see a close relationship between digitalization and environmental sustainability. That is, e-government offers a critical contributing role if long-term planning, intergenerational equity, risk reduction and resource conservation are considered in administrative planning (Burlacu et al., 2021). Like in many developed countries, various measures are put in place to ensure that e-government promotes environmental sustainability, including those related to the disposal of workstations and printers, energy saving, and waste disposal. There are also indirect measures that positively impact the environment, such as public and private sector organizations' implementation of remote workstyle or carrying out processes using information and communication technologies. Thus, digitization can reduce energy consumption or harmful emissions through a decrease in business travel and less demand for more workspace (GeSI, 2015; Zioło et al., 2022).

Importantly, worldwide trends in E-government development index (EGDI) are increasing over the years. Figure 1 indicates that the number of countries in 'Very high EGDI' and 'High EGDI' have increased by 3.02 and 4.02% respectively, while countries with average and low e-government are decreasing. Research has it that there is now increasing pressure from citizens and private sector demanding for a shift from brick-and-mortar government services to digital government operations (Zioło et al., 2022), which in part was necessitated by lockdown and curfews during the COVID-19 era (Banda, 2023). Nevertheless, there are still clear regional differences due to different levels of development across countries leading to a differentiated potential impact on sustainable development (see Appendix Figure A1 for distribution of e-government development across countries and regions), with notable lagging among LDCs in Africa and Asia.

Digitalization of government operations not only does it holds promise for enhancing government efficiency and environmental sustainability (Marcovecchio et al., 2019), it also presents implementation challenges (Basu, 2004; Krishnan and Teo, 2011; Ziolo et al., 2020) and also the significant energy consumption in the production, operation, and disposal of digital devices and overall ICT infrastructure raises the quest to probe whether the energy intensity of digitalization have benefits that exceeds the sunk costs (Belkhir and Elmeligi, 2018), hence the need for more empirical evidence for informed decision-making. Many studies have examined and confirmed the positive impact of e-government on environmental performance (Zioło et al., 2022; Lee, 2017), and so the impact of strong state capacity on environmental management (Gök and Sodhi, 2021; Kulin and Sevä, 2019; Tian et al., 2022). Noting that state failure is a big issue among Least Developed Countries (LDCs), this study feels a gap in existing literature by innovatively deploying state capacity as a contingent variable between e-government development and environmental sustainability. State capacity is a critical variable in political economy of development as it constitutes the ability of governments to effectively implement their policies and commitment to achieving them (Bastian et al., 2023; Larsson and Grönlund, 2014; Sapraz and Han, 2019; Sukarno and Nurmandi, 2023), and so is its criticality in e-government adoption for environmental sustainability.

The state is often prescribed as central in instituting measures to protect the environment. Through the implementation of regulations, for example, they can place quotas on industrial carbon emissions, safeguard deforestation, encourage the consumption of renewable energies, and set up protected areas while inhibiting unlawful wildlife trade (Kulin and Sevä, 2019; Mansbridge, 2014). Otherwise, state failure to institute regulations to protect the environment presents significant hurdles to achieving ecological sustainability, poverty reduction, and advancing innovative green technology initiatives (Andersson, 1991; Dong, 2019; Sriyakul et al., 2022). Unsurprisingly, empirical studies suggest that improving governance quality correlates with enhanced environmental health (Gök and Sodhi, 2021; Kulin and Sevä, 2019; Tian et al., 2022). On the other hand, Government ineffectiveness or the inability of the government to implement and commit to achieving

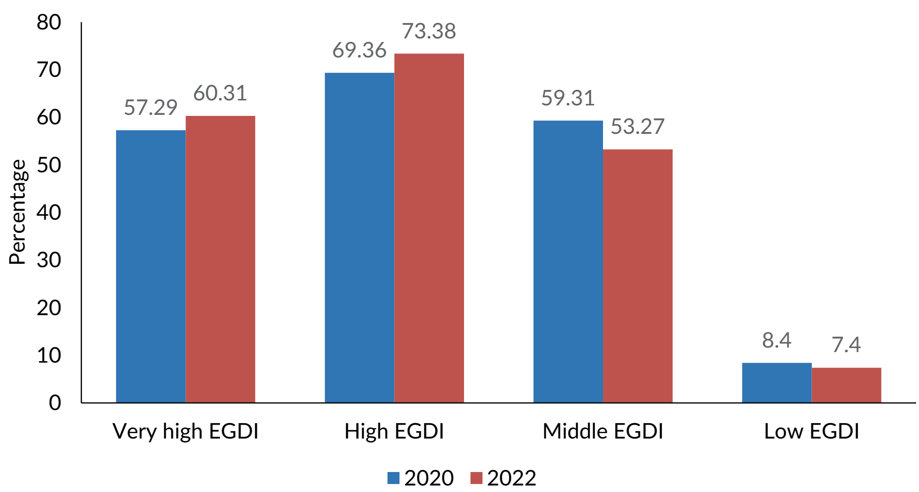

FIGURE 1
Number and proportion of countries within each EGDI grouping, 2020 and 2022. Source: Author's compilation of of United Nations E-Government Survey.

policies, therefore, constitutes a significant impediment to attaining economic goals in developing nations, including the sustainable management of natural resources (Banda, 2023a; Kulin and Sevä, 2019).

Environmental sustainability is a pressing global concern due to its indispensable provision of essential life necessities like clean water, food, and air while reserving critical resources for economic growth and providing mechanisms to mitigate natural disasters (Sapraz and Han, 2019). However, the long-term viability of the Environment is threatened by various issues including land and water degradation, deforestation, ocean acidification, desertification, greenhouse gas emissions, and climate change (Arora et al., 2018; EIF, 2023). This poses a significant risk to the livelihoods of those in Least Developed Countries (LDCs), due to increased reliance on nature for economic sustenance (Angelsen et al., 2014). Due to the fundamental importance of a healthy environment and stable climate in fostering global economic well-being, the United Nations ratified the "Transforming our World: The 2030 Agenda for Sustainable Development" document during the 2015 World Summit on Environmental Sustainability. This explains why a monotonic increase in climate research and action has been predominantly focused on the mitigation of greenhouse gas emissions, aligning with international environmental conventions such as the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol (Kim et al., 2012). However, little has been done to explore the role of the state in environmental action.

The adoption of information and communication technology (ICT) for digitalizing government operations is widely acknowledged as a key factor with substantial potential to enhance the state's capacity to deliver public services, lower energy consumption, and foster sustainable development in the 21st century (Li and Xu, 2024; Chacón et al., 2021; Zhong et al., 2022). Recent research confirms that the development of e-government improves state efficiency, effectiveness, and innovation in governance activities (Aniscenko et al., 2017; Kalu, 2019; Li and Xu, 2024; Nzimakwe and Pillay, 2010; Rodríguez-Martínez et al., 2019). Theoretically, e-government is ascribed to positively influence environmental sustainability in several ways that reduce carbon emissions such as: increasing virtual meetings and work from home arrangements which curtails business travel, and reduced utility of fossil fuels and paper (Al-Khouri, 2013; Basu, 2004; Helling et al., 2005; Jakoet-Salie, 2020), thereby minimizing carbon emissions as well as energy consumption. It is also observed that e-government eliminates the need for more workspaces thereby reducing infrastructural costs for construction as well destruction of nature (Australian Government, 2024).

In LDCs, introducing e-government in public administration is met with serious constraints (Tiika et al., 2024). For example, the rapid pace of digital technology evolution, limited internet access, gaps in digital literacy, loadshedding, and financial constraints present significant barriers to the success of e-government initiatives (Chirwa et al., 2023; Lee, 2017). Achieving a balance between technological advancement and the socio-economic context is crucial in LDCs, where disparities in access can exacerbate existing inequalities. Successful implementation of e-government in these nations requires strategic planning, capacity building, and international cooperation to address the unique challenges and harness the potential for socio-economic development.

Implementing e-government for environmental sustainability in LDCs offers a promising approach to address pressing ecological challenges while navigating limited resources and developmental constraints. Despite the potential synergies between e-government and environmental sustainability, empirical evidence still needs to be provided, particularly within the context of LDCs and mediating factors such as state capacity. Existing studies have predominantly focused on advanced economies and the nexus between ICT and environmental performance, neglecting the unique challenges and opportunities faced by technologically lagging nations (Ayub, 2022; Commander et al., 2011; Ionescu-Feleagă et al., 2023; N'dri et al., 2021). Moreover, few or no studies have explored the mediating role of state capacity in the relationship between e-government and environmental sustainability, underscoring the need for further research in this area.

The article aims to address the identified gaps in the literature by employing a multi-method approach to examine the impact of e-government on environmental sustainability in LDCs. Besides analyzing the direct effects of digitalization of government operations on environmental performance, the study will explore the contingent role of state capacity to offer insights for policymakers, practitioners, and scholars interested in e-government for sustainable development in the global South. The rest of the study is structured as follows: Section 2 outlines the materials and methods used, Section 3 presents empirical results and discussion, and Section 4 concludes the study.

2 Materials and methods

2.1 Conceptual framework and hypotheses

E-government development has emerged as an essential development indicator and an inspiration in and of itself (United Nations, 2016). As it helps governments be drawn closer to their people, it has enabled various government functionalities, thereby boosting good governance needed to achieve sustainable development (Alaaraj and Ibrahim, 2014). E-government development improves governance and rationalizes public administration, political participation, and democratization (Li and Xu, 2024; Chacón et al., 2021; Zhong et al., 2022). Other benefits of e-government include an increase in the efficiency of the delivery of government services, reduction in costs of production, exchange and consumption, time-saving, participation in decision-making, building a sense of belonging of citizens, improving the feedback loop in the enterprise world, and increase in government revenue, in addition to voice and accountability, control of corruption, and sustainable development through economic, social and environmental aspects (Zioło et al., 2022).

The current study adopts Lim's (2017) and Lee's (2017) analytical model to assess both the direct and indirect impacts of e-government development on environmental sustainability. As depicted in Figure 1, the advancement of e-government directly influences environmental sustainability. Furthermore, e-government development affects state capacity, thereby indirectly shaping environmental sustainability. In essence, the progression of e-government engenders an indirect effect on environmental sustainability by strengthening the government's commitment to environmental policies. Through this analytical framework, the objective is entering into the premature debate on mechanisms through which e-government development influences environmental sustainability (Figure 2).

Based on the analytical model illustrated in Figure 2, the study formulates three primary hypotheses as follows:

i E-government development directly influences environmental sustainability.

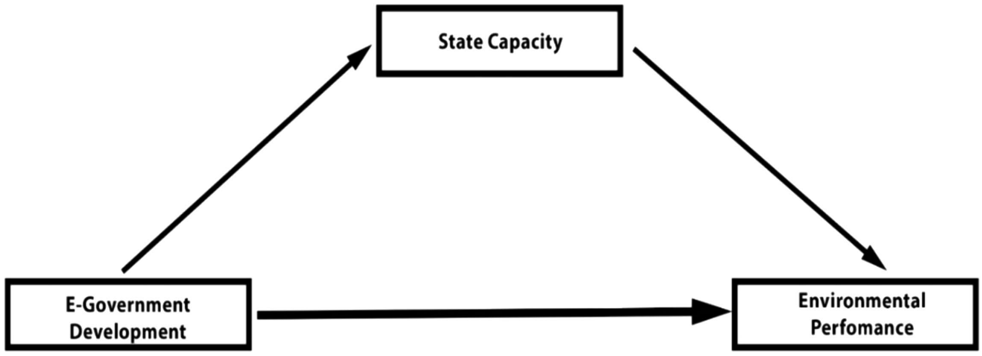

FIGURE 2
Conceptual framework. Source: Authors' analysis.

TABLE 1 Variables details.

Variable	Code	Parameter	Sign	Source
Environmental sustainability	EPI	Environmental Sustainability Index	NA	YCELP and CIESIN (2022)
E-Government	EGDI	E-Government Development Index	+ve	United Nations (2023)
State	STATE	State Capacity	+ve	Our World in Data (2023)
Greenhouse gases	CO_2	Carbon emissions	−ve	Climate Watch Data
Global warming	TEMP	Temperature	−ve	Climate Knowledge
Population	POP	Total population	−ve	WDI

Note: −ve, negative; +ve, positive. Source: Authors' compilation.

ii E-government indirectly influences environmental sustainability by enhancing state capacity.
iii Environmental impact of state capacity is positive.

Existing studies that support the relationship exhibited in the first hypothesis include Dhaoui (2022), Sriyakul et al. (2022), Lee (2017), and Krishnan and Teo (2011). Meanwhile, Lee (2017) and Lim (2017) support the relationship exhibited in the second hypothesis. An auxiliary objective that state capacity enhances environmental sustainability is supported by Gök and Sodhi (2021) who suggest that the impact of e-government development on environmental sustainability tends to be stronger when the government is committed to sustainability policies and weaker when the government commitment to environmental sustainability policies is low.

2.2 Data and variable measurement

This study utilized the 2023 list of LDCs, comprising 45 countries. Among these, 33 countries are from Africa, 8 from Asia, one from the Caribbean, and 3 from the Pacific region, as shown in Appendix Table A1. Secondary data from 2003 to 2022 were collected for these 45 countries from various international databases, including the United Nations, as detailed in Table 1. The selection of time period is based on the year of initiation and current survey output of e-government development index.

2.2.1 Measuring environmental sustainability

Like Lee (2017), Dhaoui (2022), and Krishnan and Teo (2011), we adopt the Environmental Performance Index (EPI) as a proxy for environmental sustainability due to its comprehensive nature, encompassing 40 performance indicators across climate change performance, environmental health, and ecosystem vitality categories. Studies such as Li and He (2024), Wang et al. (2023), Li et al. (2023), Sriyakul et al. (2022), and Ndour and Asongu (2024) employed climate variables such as CO2 as proxies for environmental performance.

The Environmental Performance Index (EPI) is compiled and presented by the Yale University's Center for Environmental Law and Policy (YCELP) in collaboration with the Center for International Earth Science Information Network (CIESIN) at Columbia University. It was first published in 2002 to evaluate environmental objectives outlined in the United Nations' Millennium Development Goals (MDGs). Over time, the EPI has evolved to provide essential policy tools for monitoring the United Nations' 2030 Sustainable Development Goals (SDGs), aligning with the overarching objective of guiding society towards a sustainable future. The EPI serves as a comprehensive measure of environmental sustainability on a global scale, systematically analyzing progress in addressing environmental challenges and achieving policy objectives. It covers many issues, including climate mitigation, air quality, sanitation, drinking water, waste management, biodiversity, and agriculture (Wolf et al., 2022). Notably, the EPI is measured in percentiles from zero to one hundred.

2.2.2 Measuring e-government development

Studies such as Krishnan and Teo (2011) and Lee (2017) employed the E-Government Development Index (EGDI) to gauge e-government development. The EGDI provides an assessment of e-government development status across U.N. member countries. Beyond merely appraising website development trends within a country, the index encompasses access-related factors, including infrastructure and educational levels. This comprehensive approach illustrates how different countries aspire for information technologies to enhance access and inclusivity for their populace. The index serves as a composite metric, encompassing three crucial categories of e-government: the provision of online services index (OSI), telecommunication infrastructural index (TII), and human capital index (HCI). Scores on the overall index range from 0 to 1, with countries categorized into four tiers: Very high EGDI values ranging from 0.75 to 1.00; high EGDI group values spanning from 0.50 to 0.7499; middle EGDI values extending from 0.25 to 0.4999; and low EGDI values covering the range from 0.0 to 0.2499. Banda (2023) observed that the COVID-19 pandemic led to many governments supporting electronic forms of service delivery, which may also have effects on environment sustainability.

2.2.3 Measuring state capacity

State capacity is the government machinery's capability to effectively implement and achieve its policy agenda (Banda, 2023b; Bastian et al., 2023; Besley and Persson, 2011; Dincecco, 2017; Lindsey, 2021). Notably, the proponents of the Our World in Data Index of state capacity designed the index to capture the state's capacity to sustainably raise adequate revenues, build a sufficiently skilled workforce, provide impartial security, justice, and public services, and gather accurate national statistics (Bastian et al., 2023). The index is measured on a scale that ranges from −2.5 (indicating weak) to 2.5 (indicating strong). While a strong state capacity is associated with high development sustainability, we expect the relationship to be stronger with the adoption of digital technology.

2.2.4 Measuring control variables

Consistent with previous studies, the study includes control variables such as population (Lee, 2017) and climate indicators such as CO2 and temperature that depicts human activities (Sriyakul et al., 2022; Wang et al., 2023). These variables are included to account for variations in other potential factors that may influence environmental performance but are not included in the model.

2.3 Econometric specification

To address the study objectives, the research adopts with modifications the econometric specification used in Lee (2017), which models environmental sustainability as a function of e-government, government effectiveness, and a set of control variables. Thus, the model can be expressed as:

$$EPI_{it} = \beta_0 + \beta_1 lnEGDI_{i,t} + \beta_2 lnSTATE_{i,t} + \beta_3 \left(lnEGDI_{i,t} * lnSTATE_{i,t}\right) + \beta_4 lnPOP_{it} + \beta_5 lnCO_{2,it} + \beta_6 lnTEM_{it} + \theta_t + \varepsilon_{it} \quad (1)$$

Where β_0 is an intercept; β_1, β_2, and β_3 are the main parameters being examined; control variables are denoted by parameters β_4 β_5, *and* β_6; while i accounts for the study cross-sections (1,2,…,N); t represents the time period (1,2,…,T); θ denotes year dummies; and ε is a general error term.

2.4 Estimation techniques

The study employs a multi-method quantitative technique utilizing three distinct models: one-step system generalized method of moments (SysGMM), bootstrap ordinary least squares (BOLS), and instrumental variables-generalized method of moments (IV-GMM). SysGMM serves as the foundational regression method and is applied in the primary regressions due to its ability to capture the persistence of the dependent variable. The IV-GMM is utilized to perform sensitivity analyses and ensure the robustness of findings from SysGMM and BOLS. Other studies, such as Gök and Sodhi (2021) and Zhong et al. (2022), have utilized GMM and BOLS econometric methods to model outcomes related to environmental sustainability and sustainable development.

Importantly, the IV-GMM is recommended where the estimation technique faces challenges such as correlation of units in time series, correlation of the regressor and error term, correlation of lags in a series, and heteroskedasticity. The solutions to the problem are made possible through Baum's et al. (2003) Stata-16 command. On the other hand, the consistency and efficiency of the SysGMM model outcomes depend on two critical tests: the Hansen test assessing over-identifying restrictions for instrumental validity and the Arellano-Bond test for second-order autocorrelation (AR2). The model is only deemed credible when the p-values are higher than 0.5, thus accepting the null hypotheses of no over-identifying restrictions and no autocorrelation.

3 Results and discussion

The following Table 2 presents the results of descriptive statistics performed on raw data of the study variables. The average EPI score for the full sample is 39.717 percentile, and the standard deviation of 19.092 indicates that EPI performance for individual countries is clustered around the mean score. Among sub-sample analyses, the average EPI score for LDCs in the Pacific region is the highest at 67.2 percentile, followed by LDCs in Africa at 41.585% and the Caribbean at 35.497%. Asia has the lowest average EPI score at 24.172%, supporting statistics that rank Asia as the global leading greenhouse gas emitter.

Unlike Lee's (2017) Small Island Developing States (SIDS) countries, which score slightly above 0.4, LDCs in this sample score an average of 0.222 out of 1 (22.2%) in the e-government development index. According to the United Nations classification, LDCs fall into the low EGDI values. Similarly, LDCs exhibit weak state capacity or evidence of government failure, with an average state capacity score of −0.406 on a scale of −2.5 to 2.5. The lack of government capacity suggests the poor adoption of e-government initiatives and the lack of commitment to ecocentric policies in LDCs since state capacity positively correlates with e-government development, as shown by the correlation matrix in Table 2.

TABLE 2 Basic statistics.

Summary statistics – full sample							
	EPI	EGOV	STATE	CO2	POP	PGDP	TEM
Mean-Full	39.717	0.2222	−0.4063	5.76700	19,400,000	1068.52	24.685
Mean-Africa	41.585	0.2113	−0.3914	3.59079	17,300,000	875.428	25.392
Mean-Asia	24.172	0.2759	−0.3282	16.2989	34,500,000	1309.27	21.137
Mean-Caribbean	35.497	0.1519	−1.0237	2.36737	10,100,000	1356.68	24.964
Mean-Pacific	67.214	0.2052	−0.9601	0.15842	232,165	2235.39	27.448
Std. dev.	19.092	0.1092	0.6043	11.0381	27,900,000	715.201	4.4262
Min.	0	0	−2.31	01	9,668	255.1	10.13
Max.	100	0.5777	0.7711	93.18	169,000,000	4197.2	30.01
Obs. (full)	828	460	551	817	874	833	874

Correlation matrices – full sample							
	EPI	EGOV	STATE	CO2	POP	PGDP	TEM
EPI	1.0000						
EGOV	−0.1265*	1.0000					
STAT	−0.0869*	0.4753*	1.0000				
CO2	−0.3248*	0.3207*	0.0688	1.0000			
POP	−0.2935*	0.2000*	0.0591	0.7637*	1.0000		
PGDP	0.0736*	0.2075*	0.0186	0.2333*	−0.1233*	1.0000	
TEM	0.4078*	−0.3240*	−0.1941*	−0.0099	−0.0570	−0.0052	1.0000

Source: Authors' analysis. Note: Pairwise correlation at 5% significance level.

Pairwise correlation findings reveal that e-government, state capacity, carbon emissions, and population negatively affect environmental performance. However, it is widely believed that correlation does not imply causation, allowing the researcher to delve into advanced econometric analyses to provide authentic causal inferences. The following Table 3 provides model estimation results to address the study hypotheses. Acknowledging that GMM models yield short-run coefficients, a separate simulation is run on variables significant in the short run to generate their long-run coefficients. The simulations divide the coefficient of each variable, which is significant in the short-run, by the coefficient of the lagged dependent variable subtracted from 1 (Banda, 2023b; Kripfganz and Schwarz, 2019; Shin, 2014). The computation is shown in Equation 2 below.

$$\mathrm{Lr}\mathit{VarCoef} = \frac{\mathrm{SrVarCoef}}{(1-\mathrm{b}\left[\mathrm{L1.DepVarCoef}\right)} \quad \text{or} \quad \beta_k/\left[1-\phi\right] \qquad (2)$$

Table 3 above reports empirical results from SysGMM, BOLS, and IV-GMM estimations. The results of our baseline model, the SysGMM, indicate that environmental performance is persistent, positive and statistically significant as shown by the lagged dependent variable (lnEPI_1). That is, the state of environmental performance in the previous year will likely result in a similar positive manner in the subsequent year. Studies that modelled environmental performance using dynamic econometric models also find environmental performance to be persistent (Dkhili, 2018; Ruiqian and Ramanathan, 2018).

Regarding the first hypothesis, empirical findings for the entire sample model reveal that e-government development is positive and statistically significant, confirming a direct impact on environmental performance in LDCs. These findings are consistent with the results of Dhaoui (2022), Sriyakul et al. (2022), and Lee (2017), who also found a positive relationship between e-government development and environmental sustainability. But in examining the nexus between e-government, e-business and ecological performance, Krishnan and Teo (2011) observed that the latter two offered no effect on environmental performance.

On the other hand, state capacity shows a negative and statistically significant relationship with environmental sustainability, except for the IV-GMM estimation, which depicts a positive relationship. The latter contradicts prior expectations in the third hypothesis; however, Gök and Sodhi (2021) empirically observed that government quality improves environmental management in high-income countries but not in middle- and low-income countries, like our sample of least-developed countries. This finding is not far-fetched, considering that low-income countries prioritize economic benefits and living standards over environmental sustainability (Li et al., 2023).

Interestingly, when moderated with e-government, state capacity becomes robustly positive and statistically significant in all estimators except the short-run estimation of SysGMM, thereby confirming the study's second hypothesis that e-government initiatives enhance the state's ability to implement and achieve environmentally oriented policies. Similarly, Dhaoui (2022) and Lim (2017) found that e-government improves control of corruption and government effectiveness in operations in MENA and SIDS countries, respectively.

TABLE 3 Full sample models' estimation results.

Variables	SysGMM (Short-run)	SysGMM (Long-run)	IV-GMM	BOLS
lnEPI_1	0.889*** (0.040)			
lnSTATE	−7.848** (3.11)	−7.334** (3.83)	3.05*** (11.22)	−2.75*** (2.787)
lnEGOV	2.36** (9.519)	1.119** (10.59)	8.088*** (17.319)	4.02*** (10.17)
lnEGOVSTATE	2.71 ** (12.64)	2.96** (13.92)	3.54*** (43.98)	5.58** (19.57)
lnPOP	−1.85E-08 (2.66E-08)		2.80E-08*** (4.76E-08)	1.50E-08 (7.85E-08)
lnCO2	0.028 (0.060)		−0.646*** (0.137)	−0.882*** (0.164)
Year dummies	Yes		Yes	Yes
No. of obs.	232		112	282
Wald/*F*-statistic	232.79		2805.33	2474.28
Groups/instruments	14/41			
AR(2)Prob	0.749			
Hansen statistic	0.383		0.499	
R^2			0.2174	0.7917

Source: Authors' analysis. Note: *(10%), **(5%), ***(1%), 2.66E-08 (0.0000000185), 2.80E-08(0.0000000280), (1.50E-08)0.0000000150, standard errors in parentheses, lnEGOVSTATE = lnEGOV*lnSTATE.

TABLE 4 Sub-sample models' estimation results.

Variables	AFRICA		ASIA	
	IV-GMM	BOLS	IV-GMM	BOLS
lnSTATE	2.08** (8.708)	−2.38*** (1.998)	−1.64*** (5.42)	3.56 (1.03)
lnEGOV	4.78*** (15.889)	1.45*** (8.638)	11.42 (54.14)	8.813*** (12.16)
lnEGOVSTATE	−1.15*** (3.255)	7.57*** (14.34)	4.73*** (2.299)	−5.131 (8.290)
lnPOP	9.66E-08* (5.22E-08)	1.32E-07*** (4.74E-08)	−4.00E-06*** (1.64e-06)	−3.98E-07*** (1.06e-07)
lnCO2	−0.2624 (0.5289)	−1.01*** (0.276)	9.792** (4.104)	0.782** (0.366)
Year dummies	Yes	Yes	Yes	Yes
No. of obs.	91	212	21	51
Wald/F-statistic	3408.53	2034.17	830.80	400.38
Hansen statistic	0.504		0.657	
R^2	0.3295	0.8621	0.3173	0.6887

Source: Authors' analysis. Note: *(10%), **(5%), ***(1%), 9.66E-08 (0.0000000966), 1.32E-07 (0.000000132), −4.00E-06 (−0.00000400), −3.98E-07(−0.000000398), standard errors in parentheses, lnEGOVSTATE = lnEGOV*lnSTATE.

The negative impact observed in the short run with SysGMM suggests that it will take a significant time perspective for LDCs to cope with the inexorably fast pace of digital revolution. In addition, IV-GMM and BOLS indicate that carbon emissions from human activities depict a negative and statistically significant relationship with environmental performance. For example, holding other factors constant, a one-unit increase in carbon emissions deteriorates environmental sustainability by 0.65 and 0.89 percent points, respectively.

Sub-sample analyses for Africa and Asia were conducted owing to sufficient data since GMM is suitable for scenarios where the sample (N) is larger than the time (T) (Banda, 2024). Table 4 presents regional sub-samples for comparative statistics between the two regions. While the results are broadly consistent with the findings from the entire sample, minor differences exist. For example, an increase in population is associated with an improvement in environmental performance in Africa, but the relationship is negative in Asia. This difference is unsurprising, considering that Asia constitutes roughly 61% of the world's population and may have reached its maximum carrying capacity. On the other hand, Africa constitutes about 18% of the world's population (World Population Review, 2024). In line with Weber and Sciubba's (2019) argument that an increase in population does not pose a threat to environmental performance but rather the consumption pattern of that population. The perspective suggests that differences in consumption levels caused by economic inequality, rather than population size or growth, are responsible for environmental degradation. The fact that an increase in population does not lead to environmental deterioration, therefore, makes sense considering that the continent has the highest levels of income inequality. In 2021, according to the World Inequality Database, the share of the top 10% cluster on the African continent accounted for approximately 54% of the total national income, which is more than six times the share held by the bottom 50% (Saoudi and Louis-Sarbib, 2023).

Although Asia (excluding China and India) contributes 7.55 billion tons of carbon emissions while Africa contributes only 1.42 billion tons of carbon emissions (Ritchie and Roser, 2024), sub-sample findings from IV-GMM and BOLS unsurprisingly reveal that carbon emissions improve environmental performance in Asia. We argue, therefore, that higher emissions in Asia could be associated with technological advancements and economic growth, which may positively impact environmental performance through investments in cleaner technologies and pollution control measures. Asia may also have more stringent environmental regulations or better enforcement mechanisms, which improve environmental performance despite higher emissions. In addition, countries in Asia have been leading in technological innovation and renewable energy investment, with an average growth of 32% annually since 2004 (Gupta, 2023; He et al. 2023). More likely, the benefits of renewable energy consumption help to offset the high carbon emissions in Asia, leading to improved environmental performance compared to Africa.

4 Conclusion

Theoretical expectations about the digital revolution present opportunities to enhance environmental sustainability, notably through digitizing government operations. This paper undertook an empirical investigation into the pathways through which e-government development influences environmental performance in LDCs. Employing a quantitative multi-method approach with panel data from 45 LDCs, the study finds that e-government development exerts both direct and indirect influences on environmental sustainability. The short- and long-run estimations of SysGMM reveal that a one-unit improvement in e-government development in LDCs promotes environmental sustainability by 2.36 and 1.12%, respectively. On the other hand, IV-GMM and BOLS estimations indicate that a one-unit improvement in digitalization promotes environmental performance by 8.09 and 4.02%, respectively. While state capacity to enact and commit to climate policies showed an inverse relationship with environmental sustainability, the relationship turned robustly positive and statistically significant when moderated with e-government development. For example, a one-unit improvement in the moderation effect of e-government on state capacity results in a 2.71 and 2.96% improvement in environmental performance in the short and long run, according to SysGMM. Similarly, when e-government moderates state capacity, the IV-GMM and BOLS indicate that environmental performance improves by 3.54 and 5.58% points, respectively, at *ceteris paribus*.

This study is significant because it contributes to the few studies examining the significance of e-government on environmental sustainability through the contingency role of state machinery management. Importantly, it is the first study to provide empirical evidence in Least Developed Countries. The innovation of the paper lies in its endeavor to use multiple quantitative methods and provide empirical estimations on the entire sample and sub-samples of Africa and Asia to allow for comparative analyses.

The paper's findings suggest that developing countries should strive to implement e-government development in government operations to improve environmental performance. Through digital transformation, LDCs will have the power to collect, analyze, and interpret large volumes of data, thereby generating data-driven insights for informed decisions. For example, using intelligent sensors, smart tags, drones, and blockchain technology can help private and public organizations and industries monitor energy consumption, carbon emissions, and the life cycle of products. These advantages can enable optimal resource utilization, waste reduction, energy savings, reduced carbon footprints, and proper waste disposal. Through e-government development, the state can enforce measures that strengthen institutions, such as capacity-building programs, anti-corruption initiatives, and the development of robust legal framework. However, to successfully implement e-government initiatives, LDCs need to make use of bilateral partnerships and cooperation with international organizations that can assist with expertise and financial support.

In particular, the study's lessons from Asia's sub-sample hold that LDCs should enforce stringent environmental regulations and embrace technological innovations and investment in green technology to offset industrial carbon emissions. The Asia sub-sample also suggests the need to increase investment in green technology which might have helped the region's high carbon emission to be offset.

As suggested by Lee (2017), there is a need to test the direct impact of e-government on sustainable development and, more importantly, the significance of intermediary variables such as government effectiveness and state capacity. Despite the call, empirical research on this topic has remained scant over the years, making it difficult to generalize the causal relationship between e-government and environmental sustainability. Therefore, the call remains open to researchers to test this relationship across geographical locations. We also suggest that the relationship should be tested using various mediators and econometric estimation techniques. As data points for E-government development index continue taking shape, future researchers should look to explore country specific analyses for more tailored policy recommendations. In addition, future studies should also look to unpack the composite index of e-government development to find which indicator best correlates with environmental performance.

Data availability statement

The dataset "E-government development vs environmental performance in LDCs" is available at: https://data.mendeley.com/datasets/8sk4w9sbwj/1.

Author contributions

LB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. DD: Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

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

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Appendix A

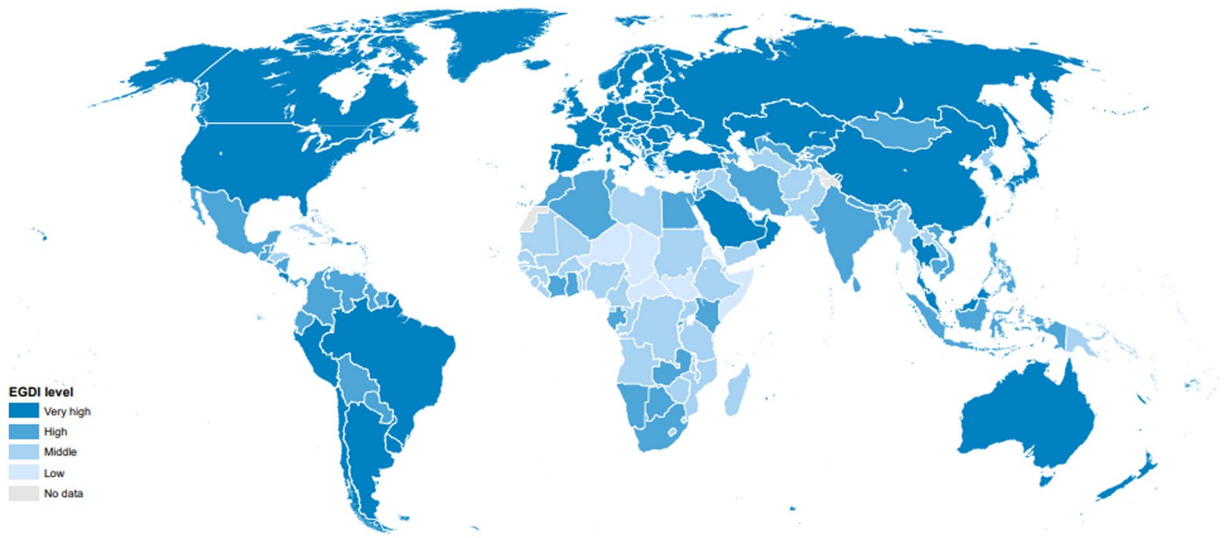

FIGURE A1
Distribution of EDGI across countries and regions. Source: 2022 United Nations E-Government Survey.

TABLE A1 U.N. list of least developed countries.

Africa (33)	Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, United Republic of Tanzania and Zambia
Asia (8)	Afghanistan, Bangladesh, Cambodia, Lao People's Democratic Republic, Myanmar, Nepal, Timor-Leste and Yemen
Caribbean (1)	Haiti
Pacific (3)	Kiribati, Solomon Islands and Tuvalu

Source: UNACTAD (2024).