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Promoting Environmental Sustainability in Africa: Evidence from Governance Synergy

Awa Traoré
Faculty of Economics and Management,
Center for Applied Economic Research (CREA),
UniversityCheikhAnta Diop, Dakar, Senegal.
E-mail: awa5.traore@ucad.edu.sn

Cheikh T. Ndour
Faculty of Economics and Management, Center for Applied Economic Research (CREA),
University Cheikh Anta Diop, Dakar, Senegal.
E-mail cheikht.ndour@ucad.edu.sn

Simplice A. Asongu
(Corresponding author)
School of Economics, University of Johannesburg, Johannesburg, South Africa.
E-mails: asongusimplice@yahoo.com, asongus@afridev.org

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Awa Traoré, Cheikh T. Ndour & Simplice A. Asongu

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Abstract

The present study complements the extant literature by assessing how environmental sustainability can be promoted by means of policies that entail the simultaneous implementation of six governance dynamics, notably, political governance (political stability/ no violence and 'voice & accountability'), economic governance (government effectiveness and regulatory quality) and institutional governance (corruption-control and the rule of law). The study focuses on 44 African countries for the period 2000 to 2020 and the empirical evidence is based on the generalized method of moments (GMM). The findings show that while the individual governance indicators positively influence carbon dioxide (CO_2) emissions, the combined or composite governance indicator has a negative effect on CO_2 emissions. Moreover, urbanization, economic growth, trade and foreign investment promote CO_2 emissions while information and communication technology in terms of mobile phone subscriptions and internet penetration have the opposite effect. Policy implications are discussed.

Keywords: CO_2 emissions, ICT, governance, urbanization, GMM model.

JEL Classification: C33, C52, 038, 040, 055

1. Introduction

For the achievement of Sustainable Development Goals (SDGs), it is recognized that an adequate balance between environmental preservation and the pursuit of prosperity must be achieved(UN, 2015). For this reason, SDG 13 emphasizes climate action to promote environmental sustainability. At the same time, following the Paris climate conference in 2015, almost all African countries have shown their interest and acted in the direction of environmental protection through nationally determined contributions to reduce their greenhouse gas emissions (GHG). Indeed, by this date, most of African countries (50 out of 54) have submitted their nationally determined contributions (AfDB, 2019). However, Africa continues to contribute positively to the growth of carbon emissions. In 2019, with 13.5% of the world's population, it contributed 3.6% of global GHG emissions (Hubacek et al., 2021). Taking into consideration the growth of carbon dioxide (CO_2) emissions, Africa is at 11% from 1990 (2.3 Gt CO2) and 10% from 2010 (0.7 16 GtCO2). In contrast, Asian and Pacific developing countries are the largest contributors with over 77% of the net increase in greenhouse gas emissions since 1990, and 83% of the net increase (6.5 Gt CO2) since 2010 (Matthews, 2016; Rocha et al., 2015; Gütschow et al., 2016).

Previous literature on CO2 emissions dynamics has focused primarily on examining the driving factors (Doğan et al., 2020; Pham et al., 2020; Nguyen et al., 2021; Shahbaz et al., 2020b). In practice, one reason, for the difficulty to significantly reduce carbon emissions in Africa is the dynamic economic growth accompanied by rapid urbanization. Work on the Kuznets environmental curve has already shown that the preservation of environmental quality remains linked to the level of development of countries, as consumption and production increase during the early stages of development (Pharm et al., 2020; Kihombo et al., 2021b). In Africa, this strong need to achieve high growth that can reduce poverty and generate resources to finance sustainable development could increase greenhouse gas emissions. Moreover, the African continent has been documented to be home to seven of the ten countries experiencing the fastest economic growth in the world (Asongu and Rangan, 2016). Furthermore, the pattern of urbanization that is taking place is contrary to the requirements of a green and low-carbon economy. Urbanization seen in recent decades could slow down the progress of environment protection and lead to consequences such as environmental degradation (Hossain, 2011). More than half of the population in Africa live in urban areas and forecasts predict a 75% urbanization rate by 2050 (United Nations, 2018).

A promising solution to this urbanization challenge and environmental protection is to significantly promote the adoption and use of new communication technologies (Ko et al. 2021; Kirikkaleli and Adebayo 2021; Cheng et al., 2021). While there are several mechanisms by which new information and communication technologies (ICTs) can affect environmental protection, one feature is its ability to radically transform production methods or modes into clean techniques through energy savings. Firstly, the adoption of new technologies helps to use renewable and conventional energy sources efficiently. In addition, it helps to improve the capacity of renewable energy, thus increasing the total supply of renewable energy to meet future energy demand. Nevertheless, although ICT can have negative impacts on carbon emissions, there is a strand of studies questioning this effect (Adebayo and Kirikkaleli, 2021; Asongu, 2018; Raheem et al., 2019; Salahuddin et al. 2016; Dauda et al., 2021; Lee and Brahmasrene, 2014).

In this context, we examine the role of ICT and urbanization in environmental preservation with particular emphasis on the importance of bundling and unbundling governance variables in view of promoting environmental sustainability by means of reducing CO_2 emissions. Accordingly, we show that the combined effect of governance is higher than the individual effects of governance dynamics. Accordingly, we show that when the considered governance indicators (political stability, voice & accountability, government effectiveness, regulatory quality, corruption-control and the rule of law) are used independently as channels, they distinctly promote environmental degradation by means of increasing CO_2 emissions. Conversely, when governance indicators are considered simultaneously after being bundled, the composite governance indicator has a negative incidence on CO_2 emission or reduces environmental degradation. This finding is important for policy makers because it informs them of whether governance policies should be implemented in isolation or collectively in the fight against CO_2 emissions in Africa.

Why Africa? Africa is largely made-up of low-income countries particularly in sub-Saharan Africa where GDP per capita in 2021 is estimated at US$ 1, 626 (World Bank, 2022).The many challenges associated with this region make it necessary to seek strong economic growth. Moreover, Africa uses less energy per capita and emits less CO_2 than other continents in the world. However, this low emission rate of African countries is not due to the use of clean energies such as nuclear energy and hydrogen representing less than 5% of the continent's electricity production(IEA). The control of emissions from African countries can be interesting(UNDP, 2022). Rwanda, for example, was the first country in Africa to revise its

NDC (Nationally Determined Contribution) by setting a target of reducing its emissions by 30% by 2030. Morocco, which holds 75% of the world's phosphate reserves, has set a target of reducing its emissions by nearly 46% by 2030. Cameroon aims to reduce its emissions by 32% by 2035 and Senegal by 21% by 2030.

Given the literature reviewed, reflecting mixed results on the impact of governance, ICT and urbanization on carbon emissions, and the stylized facts cited above, it is reasonable to assume that in order to make progress towards the 2030 SDG targets, Africa will need an inclusive policy framework. In pursuit of this goal, this study complements the extant literature by assessing how environmental sustainability can be promoted by means of policies that entail the simultaneous implementation of six governance dynamics, notably, political governance (political stability/ no violence and 'voice & accountability'), economic governance (government effectiveness and regulatory quality) and institutional governance (corruption-control and the rule of law); with an emphasis of some determinants of CO_2 emissions involved in the conditioning information set such as urbanization, economic growth, trade and foreign investment.

This study contributes to the growing literature on the determinants of CO_2 emissions within the remit of governance, not least, because governance has been established to be a prerequisite for any successful public policy and is an effective means of environmental preservation (Albitar et al., 2022; Bildirici, 2022). For example, corruption, which is a measure of good governance, directly and indirectly influences environmental quality by weakening and creating rent-seeking behavior, institutional performance, and creates barriers to effective implementation because it weakens institutional performance (Zhang et al., 2016; Wang et al. 2018). The remainder of the study is structured as follows. Section 2 provides a brief review of the literature. Section 3 describes the data and methodology. The empirical results are presented in Section 4 while Section 5 concludes with implications and future research directions.

2. Literature review

2.1. Relationship between ICT and carbon emissions

New communication technologies are drivers of strong emission reductions. They help to promote energy savings. In addition, they are fundamental for a more efficient use of renewable and traditional energy sources. In the empirical literature, many works have shown the direct and negative effects of technologies on carbon emissions (Dauda et al., 2021;

Kirikkaleli and Adebayo,2020; Zhao et al., 2021; Chen et al., 2019). For example, Dauda et al. (2021), from a dataset of African countries, for the period 1990-2018, show a bidirectional relationship between ICT and CO_2 emissions. Chen al. (2019), adopt a panel quantile regression technique for 5 OECD (Organization for Economic Co-operation and Development) countries, over the period 1996 to 2015, to show that ICT mitigates CO_2 emissions. This same result was found by Chaudhry et al. (2021) within the remit of East Asian and Pacific countries. Ali et al. (2020), for OIC (Organization of Islamic Cooperation) countries, using common correlated dynamic effects, show that ICT contributes to CO2 mitigation.

While the negative effect of ICT on carbon emissions is widely documented throughout the literature, the positive effect is les apparent. In Japan, Adebayo and Kirikkaleli (2021), using data from the period 1990-2015, tested with wavelet tools to attest the existence of a positive comovement between ICT and CO_2 emissions in the medium term and long run. This same result is supported by the study of Su et al. (2021a, 2021b) which found that an upsurge in ICT boosts CO_2 emissions in the BRICS (Brazil, Russia, India, China and South Africa) countries. For African economies, Dauda et al. (2021) using a GMM model, on data from 1990 to 2016, showed that ICTs decrease environmental quality. This same result was found in South Africa by Ko et al. (2021). Zhao et al. (2021) focusing on 62 countries over the period 2003 tov2018vuses panel data models to show a positive association between technological innovation and CO_2 emissions.

Based on the reviewed literature, there are mixed results regarding the incidence of technological innovation on CO_2 emissions employing time series and panel analysis. Therefore, this research differs by providing a robust analysis of the direct effect of technological innovation on CO_2 emissions in Africa.

2.2 Relationship between urbanization and carbon emissions

With respect to urbanization, the starting point of the theoretical review is based on ecological modernization theory showing how urbanization represents a transformation process. As societies evolve (low to middle development), environmental sustainability is taken precedence by economic growth. When societies are in higher levels of development, environmental damage becomes more significant, and societies seek ways of environmental sustainability. Thus, the negative impacts of growth on the environment can be mitigated through technological innovation, urbanization and the shift to a service economy from a manufacturing economy (Mol and Spaargaren, 2000).

In the empirical literature, the relationship between urbanization and CO_2 emissions yields mixed results: the effect can be positive (Sadorsky, 2014; Kasman and Duman, 2015), negative (Sharma, 2021, Al-Mulali et al., 2012), or not significant (Rafiq et al., 2016). Beyond the linear relationship, many authors point out that the relationship may be nonlinear and could take the forms of an inverted U-shaped (Martínez-Zarzoso and Maruotti, 2011) and a threshold effect (Cao et al., 2016). The non-linear hypothesis argues that there is an inverted U-shaped nexus between urbanization and CO_2 emissions. Indeed, it is in the initial phase of urbanization characterized by a strong expansion of infrastructure construction that an increase in CO_2 emissions is observed and in the later stages of urbanization where quality prevails that CO_2 emissions will be reduced.

2.3. Governance and carbon emissions

Regarding the effect of governance on emissions, many studies have shown a positive effect (Tamazian and Bhaskara Rao, 2010; Samimi et al., 2012; Halkos and Tzeremes, 2013; Tamazian and Bhaskara Rao, 2010; Lameira et al., 2016; Zhang et al., 2016). Indeed, Abid (2016) argues that institutional quality plays a relevant role in reducing CO_2 emissions by directly or indirectly influencing CO_2 emissions. As for democratic factors, they are related to environmental quality. Governments that are characterized by democratic standards enhance environmental quality via effective environmental regulatory systems, possibly due to the awareness of citizens and organizations that are concerned about environmental issues (Almeida and GarcíaSánchez, 2017). Finally, as for the corruption variable which is also a measure of good governance, it directly and indirectly influences environmental quality by weakening and creating rent-seeking behavior, institutional performance as well as creating barriers to effective implementation as it weakens institutional performance (Zhang et al., 2016).

3.Data and Methodology

3.1. Data

Our paper uses a panel of 44 African countries for the period 2000 to 2020 (Table A1) from the World Bank's World Development Indicators. The corresponding periodicity of the study depends on data availability constraints.

In the literature, four types of variables are commonly used to measure environmental degradation. These are per capita emissions, pollution intensity, urban concentration and total emissions. For panel data, by far the most commonly used CO_2 indicator is per capita emissions (Holtz-Eakin and Selden, 1995; MoomawandUnruh, 1997; Panayotou et al., 2000). For environmental protection, a negative sign of an exogenous variable on the outcome variable indicates favorable conditions for environmental sustainability.

Urbanization is measured by the percentage of the population living in urban areas. The choice of the urbanization variable is consistent with recent literature (Zhou et al.2013; Al-Mulali and Ozturk, 2015; BekhetandOthman, 2017). A complement of the urbanization variable which is population density is employed.

An overview of the extant literature posits that ICT can be measured in three ways. The first is ICT readiness, which focuses on the level of ICT use. The second is an articulation on ICT use, which appreciates the intensity of actual ICT use. The third way is to use an ICT impact measure, which assesses the effect resulting from effective and efficient ICT use (ITU 2009, 2010). Due to data limitations, proxies for ICT are limited to the preparation and use phases of ICT (Asongu, 2014; Amavilah et al., 2017). Primarily, we assess ICT readiness using landlines per 100 individuals and mobile cell phone subscriptions per 100 individuals.

In addition, in our study, a composite governance index is derived from principal component analysis (PCA). The composite governance variables embodies, political governance (i.e. consisting of political stability and voice & accountability), economic governance (i.e. entailing government effectiveness and regulatory quality) and institutional governance (i.e. made-up of the rule of law and corruption-control). The six governance indicators are obtained from the World Bank's World Governance Indicators.

Four more control variables are used to mitigate concerns surrounding variable omission bias. These include: (i) the growth rate of gross domestic product (GDP), (ii) trade openness (the sum of imports and exports measured as a proportion of GDP), (iii) education (gross secondary education rate), and (iv) foreign direct investment. The selection of these additional control variables is consistent with extant CO_2 emissions literature (Tamazian and Bhaskara Rao, 2010; Samimi et al., 2012; Halkos and Tzeremes, 2013; Tamazian and Bhaskara Rao, 2010; Lameira et al., 2016; Zhang et al., 2016; Asongu and Odhiambo, 2021a, 2021b).

In addition, country-specific characteristics that are not considered in the GMM specification may affect the expected signs in the estimations. The full definitions of the variables, the corresponding summary statistics, and the correlation matrix are presented in Appendix Tables A2, A3, and A4, respectively.

3.2. Methodology

In line with the underlying literature, for the GMM approach is adopted for four main factors: (i) First, the primary condition that the number of cross-sections is greater than the number of periods (Tchamyou, 2019a) within each cross-section is met because the study covers 44 countries over a 21-year period (i.e., from 2000 to 2020); (ii) the CO_2 emissions variable is persistent because its correlation coefficients with its first lag are greater than the 0.800 threshold set as a rule of thumb (Tchamyou et al., 2019); (iii) the GMM approach is compatible with a data structure that by definition should be a panel and cross-country variation is accounted for in the regressions (Asongu, 2018); (iv) endogeneity is accounted for as simultaneity or reverse causality is addressed instructively and time-invariant variables are employed to account for unobserved heterogeneity (Boateng et al., 2018).

In this study, we use the extension of Roodman (2009), Arellano and Bover (1995) to mitigate instrument proliferation (or restrict overidentification) and account for cross-sectional dependence (Baltagi et al., 2007).

The following equations in level (1) and first difference (2) articulate the estimation procedure for the standard GMM system:

$$CO_{2,i,t} = \phi_0 + \phi_1 CO_{2,i,t-1} + \phi_2 Urban_{i,t} + \phi_3 density_{i,t} + \phi_4 Gov_{i,t} + \phi_5 ICT_{i,t} + \sum_{h=1}^{4} \delta_h W_{h,i,t} + \eta_i + \xi_t + \varepsilon_{i.t} \tag{1}$$

$$\begin{aligned}\left(CO_{2,i,t} - CO_{2,i,t-1}\right) = {} & \phi_1\left(CO_{2,i,t} - CO_{2,i,t-2\tau}\right) + \phi_2\left(Urban_{i,t} - Urban_{i,t-\tau)}\right) + \phi_3\left(density_{i,t} - density_{i,t-\tau}\right) \\ & + \phi_4\left(Gov_{i,t} - Gov_{i,t-\tau}\right) + \phi_5\left(ICT_{i,t} - ICT_{i,t-\tau}\right) + \sum_{h=1}^{4}\delta_h\left(W_{h,i,t-\tau} - W_{h,i,t-2\tau}\right) \\ & + \left(\xi_t - \xi_{t-\tau}\right) + \left(\varepsilon_{i.t} - \varepsilon_{i.t-\tau}\right)\end{aligned} \tag{2}$$

$CO_{2,i,t-1}$: represents CO_2 emissions; ϕ_0 : the constant G. $Gov_{i,t}$: represents the composite index that captures the six institutional variables (political stability, voice and accountability, government effectiveness, regulatory quality, rule of law, and corruption control); W : is the vector of control variables; τ : the unit coefficient of autoregression because one year of lag is sufficient to capture past information; η_i : the time-specific constant; ζ_t : the country-specific effect $\varepsilon_{i,t}$: the error term.

In order to ensure the robustness of the estimation approach, it is useful to articulate the identification and exclusion restrictions that are worthwhile for a robust specification of the GMM model. The recent literature attests that all explanatory variables are acknowledged as endogenous whereas only time-invariant indicators are recognized as strictly exogenous (Tchamyou et al., 2019). This identification strategy was recently adopted by Boateng et al. (2018). However, it should be noted that the time-invariant variable is unlikely to reflect endogeneity after the first difference (Roodman, 2009). To examine the validation of the GMM model, four information criteria are adopted: the Arellano and Bond autocorrelation the Hansen and the Sargan tests as well as the Wald test for the overall validity of models.

3.3. Inter-individual dependence tests

In Table 1, we present the results of Peseran's (2004) cross-sectional dependence tests. For all variables, the null hypothesis of cross-sectional independence which is the position of a dependence between individuals in the panel is not rejected. Given that all p-values are equal to 0, the corresponding alternative hypothesis of cross-sectional dependence is not rejected. Hence, strong evidence of cross-sectional dependence is apparent when following Peseran (2007). Therefore, it is reasonable to move on to the second-generation stationarity tests. Second generation panel unit root tests which take into account cross-sectional dependence are now considered.

Table 1: Results of homogeneity and inter-individual dependence tests.

Hsiao homogeneity test		Inter-individual dependency test		
t-statistique	P-value		t- statistique	P-value
6.897***	0.000	Breusch-Pagan LM	1945***	0.000
9.098***	0.000	Pesaranscaled LM	44.456***	0.000
12.679***	0.000	Pesaran CD	4.103***	0.000

Source: authors' calculations

Note: ***; **; * Significance at 1%, 5% and 10% respectively

Notes: Under the null hypothesis of cross-sectional independence CD ~ N (0.1) and a p-value close to zero indicates data that are correlated across individuals in the panel, CD means the cross-sectional dependence statistic.

Table 2: Results of the Pedroni (1996) and Westerlund (2007) cointegration tests.

Pedronicointegration test (1993, 1997)			Westerlundcointegration test (2007) Ratio-variance	P-value
Modified Phillips-Perron	5.467	(0.000) **	3.745	0.000**
Phillips-Perron	-5.531	(0.000) **		
Augmented Dickey-Fuller	-5.228	(0.000) **		

Note: ***; **; * Significance at 1%, 5% and 10% respectively
Source: authors' calculations

Two cointegration tests are performed to verify the existence of a long-term equilibrium relationship between the CO_2 emission variables, the institutional variables, the urbanization variables and the ICT variables. The results in Table 2 show that the Pedroni co-integration test (Modified Phillips-Perron, Augmented Dickey-Fuller; 1981 and Phillips-Perron; 1988) is statistically significant at the 5% level. Then the null hypothesis of non-cointegration can be rejected. These results are also confirmed by the statistics of Westerlund (2007). Finally, the results validate a long-term equilibrium relationship between the different variables for the entire panel and for at least one individual in the panel.

3.4. Stationarity in the panel

The results of the stationarity tests in Table 3 show that the institutional variables are stationary in level at a threshold of 5%. The other variables in the model are stationary in first difference except for the ICT variables (the internet and mobile phone) which are stationary in second difference. These stationarity tests were performed after assessing the problem of inter-individual dependencies.

Table 3: Results of the first- and second-generation level stationarity tests.

Variables	**LLC**		**IPS**		**Decision**
CO_2	-8.9876	(0.000)	-0,484	(0,989)	I(1)
lurban	33.139	(0.000)	-2.729	(0.998)	I(1)
ldensity	-30.9248	(0.000)	12.695	(1.000)	I(2)
linternet	-4.876	(1.000)	-5.273	(1.000)	I(2)
lmobile	3,066	(1.000)	-17.286	(1.000)	I(1)
CC	-10.845	(0.002)	-1.44	(0,047)	I(0)
GE	-11.781	(0.000)	-1.956	(0.025)	I(0)
PS	-11.351	(0.000)	-2.373	(0.008)	I(0)
RQ	-5.897	(0.008)	-2.101	(0.022)	I(0)
RL	-5.154	(0.000)	-1.306	(0,092)	I(0)
VA	-4.989	(0.000)	-0.916	(0.176)	I(0)
lgdp	-1,131	(0,250)	-0,548	(0,702)	I(1)
ltrade	-4.786	(0.656)	-17.662	(0.070)	I(1)
lfdi	-5.876	(0,875)	1,784	(0,337)	I(1)

lEduc	11.101	(0,876)	-2.834	(0,081)	I(1)

Source: authors' calculations

Notes: H0 = homogeneous non-stationarity; bi = 0 for all I. t_stat is the LLC statistic and IPS the critical value associated with the different test statistics, which precede them. The value in parenthesis is the P-value. When a critical probability is greater than the critical value, then the null hypothesis is not rejected and vice versa.lurban: urbanization. ldensity: population density. linternet: internet subscription. lmobile: mobile phone penetration. CC: corruption-control. GE: government effectiveness. PS: political stability. RQ: regulatory quality. RL: rule of law. VA: voice and accountability. lgdp: GDP growth. ltrade: trade openness. lfdi: foreign direct investment. lEduc: education.

4. Empirical results and discussion

Preliminary tests of inter-individual dependence, homogeneity and cointegration of a panel were first performed. In addition, Tables A3 and A4 define the descriptive statistics and correlations between the variables, respectively. The correlation results show that the model does not suffer from multicollinearity. Table 4 below presents the empirical results specifying cross-models between CO_2 emissions, urbanization and ICT. Validation of the GMM model requires the adoption of four tests: the Arellano and Bond autocorrelation, Hansen, Sargan and Wald tests. The results show that the second-order Arellano and Bond autocorrelation test (AR [2]) takes precedence as an information criterion over the first-order test (AR [1]), and the Sargan test is not robust but is not weakened by the instruments. For the Hansen test, it is robust but weakened by the proliferation of instruments. One way to solve the problem is to use the Hansen test to avoid instrument proliferation by ensuring that the number of instruments in each specification is lower than the corresponding number of countries.

Regarding the regressions, the ICT variables (measured by internet and cell phone penetration) and the urbanization variable have a negative effect and are significant on CO_2 emissions. The density variable is positive and significant on CO_2 emissions. Most of the control variables are significant with the expected signs. The combination of ICT and urbanization can be used to mitigate the potentially negative effect of globalization on environmental degradation related to CO_2 emissions.

Table 4: CO_2 emissions, urbanization and ICT.

Variables	Model 1	Model 2	Model 3	Model 4
$CO_{2,i,t-1}$	0.925***	0.963***	0.988***	0.964***
	(0.00349)	(0.00121)	(0.000479)	(0.000821)
ldensity	-0.0292**		-0.0114***	
	(0.0132)		(0.00151)	
lUrban	1.385***			0.00208***
	(0.262)			(0.000210)
linternet	-0.0371***	-0.00131***		-0.00495***
	(0.00614)	(0.000912)		(0.00139)
lmobile	-0.110***		0.000141***	
	(0.0136)		(2.10e-05)	
lgdp	0.0127***	-0.00121	-0.00382***	-0.00504***
	(0.00343)	(0.00154)	(0.00117)	(0.00137)
ltrade	0.149***	0.0277***	0.0216***	0.0305***
	(0.00922)	(0.00750)	(0.00330)	(0.00519)
lfdi	0.0769***	0.00382**	-0.00411***	0.000466
	(0.0182)	(0.00182)	(0.00108)	(0.00138)
lEduc	0.5468	0.856	0.0089	1.257**
	(0.010)	(0.856)	(0.0089)	(0.091)
Constant	-3.956***	0.0464	0.0385	-0.0850***
	(0.742)	(0.0353)	(0.0238)	(0.0255)
Observations	864	841	837	853
Number of countries	44	44	44	44
Instruments	38	30	30	30
Wald test	6 345 .67	4 356 .98	3 987.76	4 578. 76
	(0.000)	(0.000)	(0.000)	(0.000)
AR (1) test	0.081	0.097	0.136	0.130
AR (2) test	0.161	0.171	0.178	0.183
Sargan test	0.000	0.000	0.000	0.000
Hansen test	0.052	0.174	0.233	0.165

Source: authors' calculations

Note: ***; **; * Significance at 1%, 5% and 10% respectively. lurban: urbanization. ldensity: population density. linternet: internet subscription. lmobile: mobile phone penetration. CC: corruption-control. GE: government effectiveness. PS: political stability. RQ: regulatory quality. RL: rule of law. VA: voice and accountability. lgdp: GDP growth. ltrade: trade openness. lfdi: foreign direct investment. lEduc: education.

Table 5: CO2 emissions, Governance and ICT

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
$CO_{2,i,t-1}$	0.925***	0.733***	0.303***	0.455***	0.981***	0.958***	0.956***	0.687***
	(0.00349)	(0.00111)	(0.000375)	(0.00784)	(0.000869)	(0.000994)	(0.00109)	(0.0245)
linternet	-0.0371***	-0.00131		-0.00495***	-0.00487***	-0.00801***	-0.0108***	-0.0875***
	(0.00614)	(0.000912)		(0.00139)	(0.00162)	(0.00204)	(0.00274)	(0.0085)
lmobile	-0.110***		0.00014***		0.00304*	0.00170	0.00296	-0.971***
	(0.0136)		(2.10e-05)		(0.00163)	(0.00180)	(0.00242)	(0.023)
CC	-0.0476***	0.0279***						
	(0.00365)	(0.00443)						
GE	-0.0465**		0.0171***					
	(0.0327)		(0.00279)					
PS	0.295***			0.0120***				
	(0.0336)			(0.00340)				
RL	0.00919***				0.0198***			
	(0.0168)				(0.00293)			
RQ	-0.269***					0.0429***		
	(0.0237)					(0.00548)		
VA	-0.151***						0.0407***	
	(0.0343)						(0.00824)	
G.Gov	-0.233***							-0.4567***
	(0.0411)							(0.008)
lgdp	0.0325***	-0.00121	-0.00222***	-0.00311***	-0.00452***	-0.00422***	-0.00660***	-0.00660***
	(0.00145)	(0.00485)	(0.00258)	(0.00233)	(0.00233)	(0.00157)	(0.00174)	(0.00174)
ltrade	0.203***	0.0277***	0.0216***	0.0305***	0.0277***	0.0294***	0.0141**	0.0141**
	(0.00012)	(0.00875)	(0.00660)	(0.00478)	(0.00895)	(0.00388)	(0.00247)	(0.00641)
lfdi	0.0896***	0.00442**	-0.00688***	0.00048	0.00856	-0.0424	0.00344	0.0245
	(0.0025)	(0.0212)	(0.00101)	(0.00233)	(0.00127)	(0.00241)	(0.00325)	(0.00252)
lEduc	0.275	1.235	0.007***	2.356***	0.789	0.555	0.0.58	1.586**
	(0.030)	(0.785)	(0.002)	(0.002)	(1.25)	(3.578)	(0.049)	(0.81)
Constant	-2.586***	0.0585	0.0478	-0.0785***	0.0198***	-0.0720***	(0.0339)	(0.0339)
	(0.989)	(0.0458)	(0.0423)	(0.0133)	(0.00293)	(0.0272)	-0.0280	-0.0280
Observations	837	841	864	853	860	849	849	849
Numberof countries	44	44	44	44	44	44	44	44
Wald test	12 567.87	8 976.98	9 765.87	7 985.45	11 567.87	8 975.45	6 908.45	5. 876.09
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Instruments	38	30	30	30	30	32	32	32
AR (1) test	0.091	0.087	0.245	0.111	0.136	0.130	0.130	0.130
AR (2) test	0.185	0.166	0.455	0.122	0.179	0.183	0.183	0.168
Sargan test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hansen test	0.053	0.117	0.433	0.137	0.319	0.160	0.208	0.208

Source: authors' calculations
Note: ***; **; * Significance at 1%, 5% and 10% respectively. lurban: urbanization. ldensity: population density. linternet: internet subscription. lmobile: mobile phone penetration. CC: corruption-control. GE: government effectiveness. PS: political stability. RQ:

regulatory quality. RL: rule of law. VA: voice and accountability. lgdp: GDP growth. ltrade: trade openness. lfdi: foreign direct investment. lEduc: education.

Table 6 :CO2 Emission, Urbanization, Governance and ICT.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
CO_2	0.667***	0.773***	0.688***	0.998***	0.995***	0.985***	0.999***	0.545***
	(0.00254)	(0.00147)	(0.000585)	(0.00565)	(0.00011)	(0.00123)	(0.00855)	(0.0047)
ldensity	-0.0125**		-0.0158***		2.558	0.000140***	0.000455***	-0.0128**
	(0.0111)		(0.00185)		(0.00041)	(0.0008)	(0.0004)	(0.0025)
lUrban	1.287***			0.0044***		0.000967***	0.00450***	1.252***
	(0.0025)			(0.000522)		(0.00079)	(0.00011)	(0.0.223)
linternet	-0.0585***	-0.00785***						
	(0.00113)	(0.0001)						
lmobile	-0.998***		-2.855***					
	(0.00278)		(0.00233)					
CC	-0.0476***	0.011***						
	(0.00365)	(0.00457)						
GE	-0.0465		0.0378***					
	(0.0327)		(0.00377)					
PS	0.295***			0.963***				
	(0.0336)			(0.0058)				
RL	0.00919				0.8966***			
	(0.0168)				(0.00123)			
RQ	-0.269***					0.0085***		
	(0.0237)					(0.00752)		
VA	-0.151***						0.00863***	
	(0.0343)						(0.00862)	
G.Gov								-0.345***
								(0.031)
lgdp	0.0127***	-0.00121	-0.00382***	-0.00504***	-0.00392***	-0.00422***	-0.00660***	-0.00660***
	(0.00343)	(0.00154)	(0.00117)	(0.00137)	(0.00137)	(0.00157)	(0.00174)	(0.00174)
ltrade	0.149***	0.0277***	0.0216***	0.0305***	0.0277***	0.0294***	0.0141**	0.0141**
	(0.00922)	(0.00750)	(0.00330)	(0.00519)	(0.00679)	(0.00682)	(0.00641)	(0.00641)
lfdi	0.0769***	0.00382**	-0.00411***	0.000466	0.00206	-0.000864	0.00124	0.00124
	(0.0182)	(0.00182)	(0.00108)	(0.00138)	(0.00130)	(0.00158)	(0.00181)	(0.00181)
lEduc	0.275	1.235	0.007***	2.356***	0.789	0.555	0.0.58	1.586**
	(0.030)	(0.785)	(0.002)	(0.002)	(1.25)	(3.578)	(0.049)	(0.81)
Constant	-3.956***	0.0464	0.0385	-0.0850***	0.0198***	-0.0720***	(0.0339)	(0.0339)
	(0.742)	(0.0353)	(0.0238)	(0.0255)	(0.00293)	(0.0272)	-0.0280	-0.0280
Observations	837	841	864	853	860	849	849	849
Numberof countries	44	44	44	44	44	44	44	44
Wald test	8 986.98	17 987.78	12 984.86	1 986.87	5 897.76	4 897. 43	10 876.55	7 987. 43
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Instruments	38	30	30	30	30	32	32	32
AR (1) test	0.091	0.088	0.122	0.097	0.155	0.123	0.155	0.121
AR (2) test	0.111	0.159	0.148	0.125	0.166	0.147	0.177	0.166
Sargan test	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hansen test	0.052	0.174	0.233	0.165	0.319	0.160	0.208	0.208

Source: authors' calculations

Note: ***; **; * Significance at 1%, 5% and 10% respectively. lurban: urbanization. ldensity: population density. linternet: internet subscription. lmobile: mobile phone penetration. CC: corruption-control. GE: government effectiveness. PS: political stability. RQ:

regulatory quality. RL: rule of law. VA: voice and accountability. lgdp: GDP growth. ltrade: trade openness. lfdi: foreign direct investment. lEduc: education.

It is important to note that with the introduction of governance dynamics in Tables 5 and 6, the signs of other determinants of CO_2 emissions apparent in Table 4 largely remain unchanged. Moreover, within the specific remit of governance, it is apparent from Tables 5-6 that while the individual governance indicators positively influence carbon dioxide (CO_2) emissions, the combined or composite governance indicator has a negative effect on CO_2 emissions. Moreover, urbanization, economic growth, trade and foreign investment promote CO_2 emissions while information and communication technology in terms of mobile phone subscriptions and internet penetration have the opposite effect.

With respect to the nexus of the findings with the extant literature, the literature shows that ICT can be a tool to combat environmental degradation (Awan et al., 2022; Haldar and Sethi, 2022; Lin and Zhou, 2021; Faisal et al., 2020; Ozcan and Apergis, 2017; Park et al, 2018). Regarding urbanization, when controlled, it is an environmental protection factor (Hussain et al, 2022; Kocoglu et al., 2022; Anwar et al., 2022). Considering recent research in the field, urbanization can be positively associated with CO_2 emissions (Mignamissi and Djeufack, 2021; Cheng and Hu, 2022). While governance has been established in the extant literature to mitigate CO_2 emissions (Wang et al., 2018; Asongu and Odhiambo, 2021a, 2021b; Albitar*et al*., 2022; Bildirici, 2022), in the present study such is only confirmed from the composite governance indicator and not when governance variables are considered as distinct channels in their influence on CO_2 emissions.

5. Concluding implications and future research directions

The present study has complemented the extant literature by assessing how environmental sustainability can be promoted by means of policies that entail the simultaneous implementation of six governance dynamics, notably, political governance (political stability/ no violence and 'voice & accountability'), economic governance (government effectiveness and regulatory quality) and institutional governance (corruption-control and the rule of law). The study focuses on 44 African countries for the period 2000 to 2020 and the empirical evidence is based on the generalized method of moments (GMM). The findings show that while the individual governance indicators positively influence carbon dioxide (CO_2)

emissions, the combined or composite governance indicator has a negative effect on CO_2 emissions. Moreover, urbanization, economic growth, trade and foreign investment promote CO_2 emissions while information and communication technology in terms of mobile phone subscriptions and internet penetration have the opposite effect. In what follows, policy implications are discussed.

The main policy implication is that when governance indicators (political stability, voice & accountability, government effectiveness, regulatory quality, corruption-control and the rule of law) are used independently as channels, they distinctly promote environmental degradation by means of increasing CO_2 emissions. Conversely, when governance indicators are considered simultaneously after being bundled through principal component analysis (PCA), the composite governance indicator has a negative incidence on CO_2 emissions or reduces environmental degradation. This is important for policy makers because it informs them of whether governance policies should be implemented in isolation or collectively in the fight against CO_2 emissions in Africa. It follows that the main governance policies should be implemented simultaneously, namely: (i) effective political governance in terms of the election and replacement of political leaders; (ii) appropriate economic governance within the remit of formulating and implementing sound policies that deliver public commodities and (iii) robust institutional governance especially as it pertains to the respect by citizens and the State of institutions that govern interactions between.

The findings in this study evidently leave space for future research, especially as it concerns considering how composite governance can be employed as a moderating indicator for drivers of CO_2 emissions. This study has found that urbanization, economic growth, trade and foreign investment promote CO_2 emissions. Hence, interacting composite governance with attendant drivers of CO_2 emissions to assess whether the overall incidence on CO_2 emissions is negative or not, is a worthwhile future research direction. Moreover, given the established relevance of ICTs in mitigating CO_2 emissions, ICTs could also be considered as a moderating variable in future studies.

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Appendix

Table A1: The list of countries.

Algeria	Republic Congo	Lybia	Senegal,
Angola	Cote d'Ivoire	Madagascar	Seychelles,
Benin	Egypt	Mali	South Africa
Botswana,	Equatorial Guinea	Mauritania	Sudan
Burkina Faso	Gabon	Mauritius	Chad
Burundi	Gambia	Morocco	Tanzania,
Cameroon	Ghana	Mozambique	Togo,
Cape Verde	Guinea	Namibia	Tunisia
Central African Republic	Guinea-Bissau	Niger	Uganda
Comoros	Kenya	Nigeria	Zambia
Congo Democratic	Lesotho	Rwanda	Zimbabwe

Table A2: Definitions and sources of variables

Variables	Signs	Definitions of variables (measurements)	Sources
CO2 emissions	CO_2	CO2emissions (metric tons per capita)	World Bank (WDI)
Urbanization and density variables	*Urban*	Urban Percentage of population living in urban areas	World Bank (WDI)
	density	Percentage of population by density	
Governance variables	*G.Gov*	The government index is a composite governance index following principal component analysis (PCA) to derive a weighting methodology, which better reflects the impact of each governance variable and dimension on the aggregate index (Table A5).	authors
	PS	Political stability and absence of violence/terrorism	World Bank (WDI)
	VA	Voice Democratic expression and accountability (EDemocra Composite Governance Index).	
	GE	Government effectiveness (Governance Composite Index,)	
	RQ	Regulatory quality (Governance Composite Index);	
	RL	Rule of law (governance composite index)	
	CC	Control of corruption (governance composite index).	
TIC variables	*mobile*	Mobile phone subscriptions (per 100 people)	World Bank (WDI)
	internet	Internet penetration (per 100 people)	
Control variables	*gdp*	Population growth rate (annual %)	World Bank (WDI)
	Educ	Pupil teacher ratio in secondary education	
	Trade	Imports plus exports of goods and services (% of GDP)	
	fdi	Foreign direct investment inflows (% of GDP)	

Source: authors' compilation
Source: WDI, World Bank Development Indicators

Table A3: Summary Statistics.

Variable	Obs	Mean	S.D	Min	Max
CO2	924	1.393	2.203	.016	11.676
lUrban	924	1.182	.552	-4.999	2.447
ldensity	924	3.716	1.35	.779	6.435
linternet	924	1.528	1.746	-5.132	4.432
lmobile	924	3.258	1.684	-4.012	5.17
CC	924	-.62	.636	-1.816	1.23
GE	924	-.677	.636	-2.009	1.217
PS	924	-.519	.893	-2.699	1.282
RQ	924	-.63	.589	-2.347	1.127
RL	924	-.648	.635	-1.97	1.077
VA	924	-.585	.709	-2.001	.983
G.Gov	924	-0,583	0,213	-0,211	0.634
lgdp	924	11.716	2.221	1.389	15.934
ltrade	924	4.136	.565	-.243	5.416
lfdi	924	.784	1.348	-6.256	4.165
lEduc	924	13.069	1.593	8.87	16.344

Source:authors' compilation

Note:obs: observations; Mean: average; SD: standard deviation; Min: minimum; Max: maximum

CO2 : carbon dioxide emissions. lurban: urbanization. ldensity: population density. linternet: internet subscription. lmobile: mobile phone penetration. CC: corruption-control. GE: government effectiveness. PS: political stability. RQ: regulatory quality. RL: rule of law. VA: voice and accountability. lgdp: GDP growth. ltrade: trade openness. lfdi: foreign direct investment. lEduc: education.

Table A4: Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) emi_CO2	1.000															
(2) lUrban	0.518	1.000														
(3) ldensity	-0.13	-0.29	1.000													
(4) linternet	0.299	0.47	0.171	1.000												
(5) lmobile	0.216	-0.40	0.080	0.880	1.000											
(6) CC	0.195	0.172	0.073	0.289	0.203	1.000										
(7) GE	0.263	0.21	0.038	0.276	0.174	0.873	1.000									
(8) PS	0.311	0.25	0.02	0.171	0.130	0.692	0.642	1.000								
(9) RL	0.077	0.06	0.068	0.191	0.152	0.781	0.867	0.575	1.000							
(10) RQ	0.211	0.192	0.107	0.324	0.221	0.897	0.903	0.721	0.863	1.000						
(11) VA	0.035	0.090	0.085	0.210	0.167	0.756	0.699	0.555	0.728	0.790	1.000					
(12) lgdp	-0.02	-0.13	-0.13	-0.02	-0.13	-0.16	-0.02	0.005	-0.12	-0.04	-0.56	1.000				
(13) ltrade	0.366	0.393	-0.15	0.208	0.208	0.320	0.274	0.433	0.149	0.277	0.239	0.323	1.000			
(14) lfdi	0.054	0.255	-0.20	0.109	0.155	0.121	0.119	0.212	0.096	0.147	0.056	0.348	1.000	1.000		
(15) lEduc	-0.16	-0.01	0.082	0.113	0.108	-0.25	-0.05	-0.50	0.009	-0.15	-0.15	-0.39	-0.15	-0.47	1.000	
(16) G.Gov	0.23	0.35	0.45	-0.97	-0.30	-0.46	-0.06	0.06	-0.23	-0.09	-0.45	-0.45	-0.56	-0.34	-0.02	1.000

Source:authors' compilation

Table A5: Principal Component Analysis (PCA)

Component	Eigenvalue	Proportion	Cumul	Difference	F1	F2	F3
CC	4.786	0.7976	0.7976	4.329	0.915	0.19	-0.227
GE	0.457	0.0762	0.8738	0.084	0.931	-0.139	-0.237
PS	0.372	0.0620	0.9358	0.152	0.788	0.600	0.075
RQ	0.219	0.0365	0.9723	0.128	0.907	-0.242	0.032
RL	0.091	0.0151	0.9874	0.015	0.966	-0.029	-0.083
VA	0.075	0.0125	1.000	0.034	0.840	-0.136	0.501

Source : authors' calculations
Note: Proportion represents the share of each component. Cumulative represents the sum of the increasing proportions. Difference represents the eigenvalue of the first component and that of the second component. F1, F2 and F3 are factorial axes of the component matrix.