

The diffusion of green technology, governance and CO₂ emissions in Sub-Saharan Africa

Green
technology and
CO₂ emissions

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Abstract

Purpose – A promising solution to meet the challenge of sustainability and ensure the protection of the environment consists in acting considerably on the adoption and use of new information and communication technologies. The latter can act on the protection of the environment; completely change manufacturing processes into energy-efficient, eco-friendly techniques or influence institutions and governance. The article attempts to cover shortcomings in the literature by providing a couple of theoretical frameworks and grounded empirical proofs for the dissemination of green technologies and the interaction of the latter with institutional quality.

Design/methodology/approach – The sample is made up of 43 African countries covering the period 2000–2020 and a panel VAR modeling approach is employed.

Findings – Our results show that an attenuation of CO₂ emissions amplifies the diffusion of digital technologies (mobile telephones and Internet). Efficiency in the institutional quality of African countries is mandatory for environmental preservation. Moreover, the provision of a favorable institutional framework in favor of renewable energy helps to stimulate environmental performance in African states.

Originality/value – This study complements the extant literature by assessing nexuses between green technology and CO₂ emissions in environmental sustainability.

Keywords CO₂ emissions, Green technology, Governance, VAR model

Paper type Research paper

1. Introduction

Since the 1990s, environmental degradation has caused great concern around the world. The need to include sustainability in the economic model in order to encourage economic actors to take environmental concerns into account is acute. The production model based on the search for infinite growth has created environmental problems such as extreme climatic events that compromise agricultural production levels, the reduction of biodiversity, as well as the depletion of resources available at the scale of the world and more particularly in Sub-Saharan Africa (Alam *et al.*, 2007; Asongu *et al.*, 2016, 2020; Abdulqadir, 2021, 2022, 2023; Fakher *et al.*, 2023).

A promising solution to meet this sustainability challenge and ensure environmental protection is to act considerably on the adoption and use of new information and communication

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technologies (Ko *et al.*, 2021; Adebayo and Kirikkaleli, 2021; Cheng *et al.*, 2021). If there exist mediating channels through which information and communication technologies (ICTs) can influence the protection of the environment, a particular characteristic is its capacity to radically transform the methods or the modes of production into clean techniques by energy savings. In addition, it participates in strengthening renewable energies' ability, thereby leveling the amount of renewable energies needed for future purposes. However, despite the detrimental effects of ICTs on carbon emissions, a substantial volume of empirical works interrogate this outcome (Adebayo and Kirikkaleli, 2021; Asongu, 2018; Raheem *et al.*, 2020; Su *et al.*, 2021a, b; Salahuddin *et al.*, 2016; Dauda *et al.*, 2021; Lee and Brahmasrene, 2014; Majeed and Svendsen, 2018).

In this context, the development and transfer of green technologies are essential for achieving the 2030 Sustainable Development Goals (SDGs) and act as a catalyst for social, economic and environmental cornerstones (Lema and Lema, 2012; N' dri *et al.*, 2021). The implementation of green technology requires changes in the productive structure, which must be supported by economic incentives, as well as policy measures specific to the socio-economic realities of Sub-Saharan African countries. Green technologies encompass the emergence and implementation of by-products, equipment and processes adopted to conserve the environment. Energy-efficient technology is considered a combination of technology, emission reduction, energy efficiency technologies and renewable energy technology (Hottenrott *et al.*, 2016; Du *et al.*, 2019). These technologies should meet the growth needs of Sub-Saharan African countries in a way that they transition overtime without necessarily harming natural resources.

Green technologies are therefore an essential tool for achieving sustainable growth and insofar as they guarantee the satisfaction of the needs of present and future generations, they therefore represent an opportunity for growth. Green technologies such as environmentally friendly processes and products, are less harming, efficient in resource utilization, waste and products re-useable and adequate residual waste management (Traoré *et al.*, 2023). Green technological innovation can reduce energy consumption, decrease polluting emissions, improve environmental quality and promote the development of a greener economy (Wang *et al.*, 2021). Green technology relates to diversified fields such as biofuels, eco-forestry, renewable energies and solid waste management. However, it is neither viable nor necessary to adopt all green technologies without considering the country-specific institutional framework.

Furthermore, there is a direct link between ICT and institutions. The latter being defined as a set of habits or common rules of the game, norms or laws influencing relations and interplays between individual agents and groups (Edquist, 1997). They allow the implementation of effective environmental policies to reduce greenhouse gases. Also, institutions can contribute to the implementation of environmental protection measures aimed at reducing carbon emissions (Ibrahiem, 2020; Teng *et al.*, 2021).

According to the World Bank (2022), between 2010 and 2020, 1.3 billion people were able to be connected to electricity, but 733 million are still not, of whom 77% (568 million) live in sub-Saharan Africa. The energy sector in Africa can be clustered under three main regions. The first region being North Africa, is predominantly dominated by oil and gas. South Africa on the other hand, relies on coal meanwhile; the remaining region of sub-Saharan Africa is heavily dependent on biomass energy. Considered as an extensive range of fossil fuels englobing wood, agricultural and animal wastes, as well as charcoal, biomass energy however is commonly used in its unprocessed raw state (Karekezi, 2002; Karekezi *et al.*, 2003).

The main reason to focus on sub-Saharan Africa (SSA) is that the majority of the population does not have access to electricity, which leads to energy poverty and the need for new discoveries of energy supplies. Out of the 883 million inhabitants in sub-Saharan Africa, close to 585 million people lacked access to electricity in 2009, a figure that could rise to 652 million by 2030.

Most countries in Africa are bequeathed with abundant renewable energy resources. However, their lack of expertise, mismanagement and an unfavorable institutional framework constitute obstacles to their development. Despite this lag, it is recognized that technology may take time to diffuse into widespread use, due to the heterogeneity of economic agents (Young, 2010; Nwulu *et al.*, 2011). This also applies to eco-friendly technologies given that, agents are not equally exposed to greener technologies nor encounter similar learning paths due to their socio-economic characteristics. The social background in Sub-Saharan Africa and individual preferences are different depending on the agents. As compared to traditional technologies, green technologies possess ample diffusion processes and potentially mitigate carbon emissions.

Some studies have shown that innovations in eco-friendly technologies and renewable power consumption, significantly dampen CO2 emissions (Azam *et al.*, 2021a, b; Teng *et al.*, 2021). On the other hand, the quality of institutions, economic growth and the consumption of renewable energy exacerbate CO2 emissions (Inglesi-Lotz and Dogan, 2018; Adams and Acheampong, 2019; Adekoya *et al.*, 2021). Furthermore, green technological innovation and the quality of institutions are considered as important channels to lower carbon emissions and spur sustainable development (Obobisa *et al.*, 2022). The work of Xie *et al.* (2022) examined the effect of technological innovation and renewable energy on CO2 and found that a 1% increase in structural change and economic growth leads to an increase in CO2 of 1.600 and 0.819%.

Furthermore, over a sample of 23 most industrialized countries, Comin and Hojiin (2004) investigate on the diffusion of 20 technologies for the period 1788–2001. The authors find that, new technologies share similar effects. In a subsequent paper, Comin *et al.* (2010) study 15 technologies in 166 economies over the past two centuries, and stipulate that the average time of adoption is 45 years and less for newer technologies after invention.

Ultimately, the emergence of green technologies constitutes one of the major transformations of this decade, affecting the economies of the world. This article aims to examine the impact of the process of introducing green technologies on institutions in 43 countries in Sub-Saharan Africa over the period 2000 to 2019. The interaction of green technologies with institutional quality has lightly been addressed in the literature, although this interaction is of relative importance, especially for economic policy-making. As we shall observe in Section 2 in relation to the extant literature on the subject, very few works have thus, focused on this very important underlying concern, especially from an institutional point of view.

So why do institutions matter in the dissemination process of green technologies in Sub-Saharan Africa? The argument being that they interact, diffusion is thus a product of this interaction. Green technologies as essential elements in the fight against global warming, are used by economic agents to carry out their transactions and ultimately reduce their carbon emissions. However, the scale and intensity of the use of green technologies depends on the institutions and it is this dependence that is studied in this work.

The article contributes to the existing body of the literature in several ways. First, this study provides a couple of theoretical channels and empirical evidence for the diffusion of green technologies and the interaction of the diffusion process with institutional quality using panel vector autoregressive (VAR) modeling in the examination of interrelationships which constitutes a hybrid methodology between classical panel models and VAR models.

Moreover, the underlying methodology is appropriate, because it takes into account the individual specificities of each country in our sample and does not make any *a priori* restriction on the exogeneity and endogeneity of the variables. In addition, it makes it possible to grasp both static and dynamic interdependencies and allows a major analysis of impulse response functions. In summary, the present study complements the body of existing knowledge and distinguishes itself from previous ones by highlighting the fundamental cause of green technologies in Sub-Saharan Africa, where there are few or no empirical studies. Hence, the corresponding research question of the study is the following: how can environmental protection be promoted through the diffusion of green technology and governance in sub-Saharan Africa?

The rest of the study is organized as follows: section two describes the literature review, the mechanisms involved in the process of diffusion of green technologies, and its interaction with institutions. Section three describes the data and methodology, section four covers the results and discussion, while section five entails the conclusion and policy recommendations based on the findings of the study.

2. Literature review

This section summarizes some of the literature and theory that underpins the process of green technology diffusion, as well as how institutional aspects can affect the process of technological change on CO₂ emissions.

2.1 Theoretical framework

The theoretical framework is discussed in two main strands especially as it pertains to the nexus between governance and environmental quality on the one hand and on the other, the linkage between information technology and environmental quality. The two strands are discussed in the same chronology as highlighted.

In the first strand, consistent with contemporary environmental sustainability literature (Traoré *et al.*, 2023), from a theoretical standpoint, the system of governance can influence environmental quality, especially as it pertains to the importance of good governance in the allocation of relevant resources needed to reduce levels of environmental pollution. Furthermore, when an institutional environment is favorable, there is less bureaucracy linked to designing and implementing effective measures for tackling environmental concerns (Salman *et al.*, 2019). According to the narrative, reduced costs of transaction are favoured by good governance which motivates the theoretical importance of governance quality in environmental protection. Considering the World Bank governance indicators that are used in the present study, the theoretical literature is supportive of their importance in mitigating environmental pollution. For instance, corruption-control enables an effective means by which CO₂ emissions can be curbed through well tailored governance measures (Hosseini and Kaneko, 2013), not least, because corruption is very apparent in the environmental sector (Leitao, 2016; Abid, 2016) and corruption is also linked to the cost of reducing environmental pollution (Wang *et al.*, 2018).

In the second strand, the theoretical basis for the diffusion of information technologies in environmental sustainability is premised on the perspective that, information technology reduces cost that otherwise would have been allocated to activities that engender environmental pollution such as CO₂ emissions (Asongu *et al.*, 2018). For instance, the use of information technology can limit transportation and other costs linked to production activities; hence, reduce CO₂ emissions owing to, *inter alia*, mitigated information asymmetry (Tchamyou, 2019).

2.2 Dissemination of green technologies

Numerous studies have examined the empirical links between technological progress and environmental damage (Fagbohunge *et al.*, 2019). New communication technologies are engines for strongly reducing pollutant emissions. They participate in the promotion of energy savings and stand as prerequisites for a more cost-efficient use of renewable and traditional energy sources (Dauda *et al.*, 2021; Adebayo and Kirikkaleli, 2021). The environmental crisis that the world economy is going through requires the establishment of productive systems that meet both the requirements of competitiveness and sustainability from economic, social and environmental points of view. At the international level, market demands have increased by emphasizing the use of more efficient processes that guarantee product quality and respect for the environment. Therefore, the use of green technologies implies the optimization of production processes with a view to protecting the environment (Sun *et al.*, 2019).

Thus, the role of green technologies supplements both climate change and environmental sustainability. In addition, green technological innovations help countries optimize their usage of renewable resources, which reduces CO₂ emissions (Ulucak, 2021). However, controversy remains over the two-way link between green technologies and carbon emissions with researchers providing varied results.

The literature on the effects of green technology on carbon emissions in African economies is scanty. For instance, by employing Engle-Granger causality and an error correction model for a sample of 17 African states over the period 2001 to 2014, Youssef *et al.* (2018) found that green technology innovation and institutional quality stimulate sustainable growth. Dauda *et al.* (2021) found that green technology abridged CO₂ emissions in Egypt, Mauritius and South Africa from 1990 to 2016. Subsequently, Ibrahiem (2020) found that technological innovation is significant to diminish CO₂ emissions in Egypt. Other authors obtained varied results based on their sample. For instance, Khattak *et al.* (2020) found that innovation significantly reduces environmental quality in South Africa, India, China and Russia, while the opposite is obtained in the case of Brazil. Du *et al.* (2019) found that green innovations have no significant effect on mitigating CO₂ emissions in developing countries, but are effective in advanced economies.

Thus, green technologies are defined as goods and services capable of measuring, preventing and limiting pollution, improving the environmental conditions of air, water, problems related to soil, waste and noise, accessible, adaptable and available in developing countries' markets for distribution, use and export. In this same perspective, a green technology is identified in several ways: allowing the reduction of emissions and/or discharges of a pollutant, or the reduction of electricity and/or water consumption, without causing an increase in other contaminants (Traoré *et al.*, 2023). Thus, the decision to use green technologies is complex, subject to multiple influences and is therefore difficult. Hence, it is necessary to analyze the internal and external factors of the organization that influence this decision which considers the actors and the pressures from different sources that have an impact on this decision, as well as the technological responses provided (Asongu *et al.*, 2018).

2.3 Institutions, renewable energy consumption and CO₂

The importance of institutions has widely been acknowledged in the literature since the seminal work of North (1991) who highlighted the relative importance of institutions in enhancing the functioning of advanced economies as well as a driving role in the change of the real economy. The environmental quality of a country hinges on its governmental institutions, irrespective of the level of GDP, since pollution will intensify in countries with frreaking environmental regulations (Egbetokun *et al.*, 2020). The use of renewable energies and the achievement of sustainable development are possible thanks to the efficiency of institutions. These conclusions have been reinforced by other works in recent years.

With respect to the effect of governance on emissions, a volume of empirical works have shown a positive effect (Tamazian and Rao, 2010; Samimi *et al.*, 2012; Halkos and Tzeremes, 2013; Lameira *et al.*, 2016; Zhang *et al.*, 2016). Indeed, Abid (2016) argues that institutional quality is vital in reducing CO₂ emissions through its direct or indirect influence on CO₂ emissions. Regarding the democratic factors, they are related to the quality of the environment. Democratic governments improve the quality of the environment through effective environmental regulatory systems, perhaps due to the alertness of both the citizens and organizations concerned about environmental issues (Almeida and García-Sánchez, 2017).

In sub-Saharan African countries, studies have concluded that institutional quality is crucial for mitigating CO₂ emissions. Indeed, political stability, government efficiency, democracy and control of corruption reduce CO₂ emissions, while regulatory quality and the rule of law boost CO₂ emissions (Abid, 2016; Teng *et al.*, 2021; Azam *et al.*, 2021a, b). By adopting the fixed and random effects techniques for the period 1980 to 2015, Acheampong *et al.* (2019) found that institutional quality has minor effects in reducing CO₂

emissions in sub-Saharan Africa. Research work by [Haldar and Sethi \(2021\)](#) opined that institutional quality condenses CO2 emissions. Studies on the link between the issue of institutional quality and CO2 emissions in African countries have contributed a lot to the literature. However, research on the effects of green technology and institutional quality on CO2 emissions in African countries is sparse.

The increase in global temperature and the reduction of CO2 emissions to net zero have resulted in serious environmental calamities ([Obobisa, 2022](#)). This CO2 emission requires the use of renewable energies which involves the consumption of fossil fuels. The components of wind power, solar power and ocean power are the renewable energy sources to cope with climate change and global warming ([Kenner and Heede, 2021](#); [De La Peña et al., 2022](#)).

The literature on the interaction between renewable energy use and CO2 emissions has made important contributions. Indeed, the work of [Yuan et al. \(2022\)](#) supported this interaction and found that a reduction in CO2 emissions is supported by renewable energy, indicating that renewable energy is very good at achieving carbon neutrality.

Along the same lines, in South Africa, findings have shown that economies dependent on fossil fuels need to diversify their energy portfolios by integrating renewable energy supplies to reduce CO2 emissions ([Sarkodie and Adams, 2018](#); [Adams and Acheampong et al., 2019](#); [Namahoro et al., 2021](#)) and non-renewable energies to increase CO2 emissions ([Inglesi-Lotz and Dogan, 2018](#)). However, other works have shown that the non-renewable and renewable aspects of energy both contribute to CO2 emissions in Sub-Saharan African countries ([Inglesi-Lotz and Dogan, 2018](#); [Adams and Nsiah, 2019](#)).

Building on the narrative in the introduction, especially as it pertains to the contribution of this study to the extant literature as well as on the theoretical and empirical literature covered in this section, the following hypothesis is tested within the remit of the study.

- H1.* The diffusion of green technology and governance promote environmental protection in Sub-Saharan Africa.

3. Methodology

3.1 Empirical specification

The literature review has enabled the present study to identify the variables likely to impact institutions and technological diffusion. Since the objective is to study the joint dynamics of the two phenomena, modeling based on a panel autoregressive vector (PVAR) is more appropriate to take into account the simultaneity of the link.

This paper uses panel VAR modeling developed by [Love and Zicchino \(2006\)](#) and [Abrigo and Love \(2016\)](#). The use of this approach in examining the interrelationships between different macroeconomic variables has generated great enthusiasm in the empirical literature because it constitutes a hybrid methodology between classic panel models and vector autoregressive (VAR) models.

The panel VAR (PVAR) model clusters the traditional VAR approach which considers all the variables of the system as endogenous with the panel data approach which makes it possible to take into account unobserved individual heterogeneity. Thus, we use PVAR modeling as part of the Generalized Method of Moments (GMM) to achieve our goal. Based on the work of [Abrigo and Love \(2016\)](#), the PVAR model is specified as follows:

$$Y_{it} = A_1 Y_{it-1} + A_2 Y_{it-2} + A_3 Y_{it-3} + \dots A_p Y_{it-p} + B X_{it} + u_{it} + e_{it} \quad (1)$$
$$i \in \{1, 2, \dots, N\}, t \in \{1, 2, \dots, T_i\}$$

where Y_{it} is a vector ($1 \times k$) of endogenous variables; X_{it} is a vector (1×1) exogenous variables; u_i and e_{it} are vectors ($1 \times k$) dependent variable-specific fixed effects and idiosyncratic (intrinsic) errors, respectively. The parameters at the top are estimated together

with the fixed effects; alternatively, independently of the fixed effects after transformation, using the equation-by-equation ordinary least squares (OLS).

3.2 Presentation and preliminary analysis of data

The sample is made up of 43 African countries covering the period 2000–2020 (Table A1) from the World Bank Development and World Governance Indicators of the World Bank. The list of countries is provided in Table A1 while Table A2 discloses the variables and corresponding sources. The corresponding periodicity of our study is influenced by the constraints related to the availability of data. Finally, the PVAR model retained is a simple 6-variable model which can be represented as follows:

$$\begin{bmatrix} 1a_{12}a_{13}a_{14}a_{15}a_{16} \\ a_{21}2a_{23}a_{24}a_{25}a_{26} \\ a_{31}a_{32}3a_{34}a_{35}a_{36} \\ a_{41}a_{42}a_{43}4a_{45}a_{46} \\ a_{51}a_{52}a_{53}a_{54}5a_{56} \\ a_{61}a_{62}a_{63}a_{64}a_{65}6 \end{bmatrix} \begin{bmatrix} CO2_{i,t} \\ REC_{i,t} \\ Internet_{i,t} \\ Mobile_{i,t} \\ gdp_{i,t} \\ Inst_{i,t} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \\ a_{30} \\ a_{40} \\ a_{50} \\ a_{60} \end{bmatrix} + \begin{bmatrix} L_{11}L_{12}L_{13}L_{14}L_{15}L_{16} \\ L_{21}L_{22}L_{23}L_{24}L_{25}L_{26} \\ L_{31}L_{32}L_{33}L_{34}L_{35}L_{36} \\ L_{41}L_{42}L_{43}L_{44}L_{45}L_{46} \\ L_{51}L_{52}L_{53}L_{54}L_{55}L_{56} \\ L_{61}L_{62}L_{63}L_{64}L_{65}L_{66} \end{bmatrix} \begin{bmatrix} CO2_{i,t-p} \\ REC_{i,t-p} \\ Internet_{i,t-p} \\ Mobile_{i,t-p} \\ gdp_{i,t-p} \\ Inst_{i,t-p} \end{bmatrix} + \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \\ \mu_6 \end{bmatrix} \quad (2)$$

with $Y_{i,t}$ a vector with 6 variables considered to be endogenous and exogenous simultaneously: CO2 designates carbon dioxide emissions; REC, the consumption of renewable energy (i.e. it is the addition of the consumption of hydroelectric, nuclear, solar, wind and biomass energy); Internet penetration rate per 100 people, mobile cellular phone subscriptions per 100 people, *Inst* shows an index determining institutional quality, GDP per capita (*gdp*) reflects the level of development of countries and their ability to continue growth in productivity. The 6*6 matrix L contains the coefficients of the interrelations between the 6 variables and the 6*1 matrix U contains the error terms. The study's REC variable was expressed as a natural logarithm, to ensure that the variables conform to the normal distribution, to reduce the problem of heteroscedasticity.

3.3 Inter-individual dependence and panel stationarity tests

PVAR modeling requires prior stationarity tests. There is a large literature on panel root testing, of which Hurlin and Mignon (2005) summarized, and they presented the first- and second-generation unit root tests. In this study, we propose the cross-sectional dependence test developed by Pesaran (2004) before choosing the type of stationarity test. If the cross-dependencies are verified, we will offer the second-generation test (CIPS); if they are not verified, we will limit ourselves to the first-generation test (Levin *et al.*, 2002; Im *et al.*, 2003). After transforming Equation (1) above, Abrigo and Love (2016) suggest that the GMM estimator be represented as follows:

$$\left(\overline{Y^*}' Z \widehat{W} Z' \overline{Y^*} \right)^{-1} \left(\overline{Y^*}' Z \widehat{W} Z' \overline{Y^*} \right) \quad (3)$$

with $\widehat{W}$ the matrix of rank weights ($L * L$) assumed to be non-singular, symmetric and positive. Weights are often used to maximize efficiency. We suppose that $E[Z'e] = 0$ and that the rank $E[\overline{Y^*}' Z] = kp + l$

4. Results and discussions

Before the main estimate, the preliminary null hypothesis tests of independence of Pesaran (2004) and those of unit root of Pesaran *et al.* (2008) were carried out in order to solve the problems of the panel data in Tables 2 and 3, respectively. In addition, Table 1 which defines the statistical results showed that the dispersion of the technological variables is low. Indeed, the average number of mobile phone subscribers is 55.413 and that of the number of Internet subscribers is 13.01 respectively, 46.24 and 66.554 in dispersion. However, the dispersion of renewable energy consumption (REC) is strong, with an average of 257,000 and dispersion of 621,000. This shows a high inequality of REC in the area.

In Table 2, we present the results of cross-dependency tests. For all the variables, we fail to reject the null hypothesis of cross-sectional independence in favor of dependence between the individuals

Table 1.
Descriptive statistics

Variable	Obs	Mean	Std.Dev	Min	Max
CO2	903	1.247	1.954	0.016	9.384
REC	903	257,000	621,000	28.867	4,540,000
Internet	903	13.041	16.556	0.006	84.12
Mobile	903	55.413	46.24	0	175.873
gdp	903	11.464	2.199	1.389	15.52
Inst	903	0	4.783	-10.93	12.62

Note(s): The table summarizes the annual statistics of various variables in our sample. It compromises the number of observations (Obs), standard deviations (Std.Dev), minimum (Min) and maximum (Max)

Source(s): Authors

Table 2.
Results of the test of
the null hypothesis of
independence
(Pesaran, 2004)

Variable	CD-test	<i>p</i> -value	corr	abs(corr)
CO2	44.96	0.000	0.327	0.573
REC	64.10	0.000	0.466	0.685
Internet	123.55	0.000	0.898	0.898
Mobile	124.17	0.000	0.903	0.903
gdp	55.38	0.000	0.403	0.662
Inst	2.07	0.038	0.015	0.420

Note(s): Under the null hypothesis of cross-sectional independence $CD \sim N(0,1)$ and a *p*-value close to zero indicate data that are correlated between panel individuals, CD signifies the cross-sectional dependence

Source(s): Authors

Table 3.
Results of the unit root
tests of Pesaran (2007)
on the level series

Tests carried out on the series in level				
Tests	<i>t</i> -statistics	critical-value	T	NT
CO2	-2.187	-2.61	21	903
REC	-1.944	-2.61	21	903
Internet	-1.97	-2.61	21	903
Mobile	-2.658	-2.61	21	903
gdp	-1.818	-2.61	21	903
Inst	-2.274	-2.61	21	903

Note(s): H_0 = homogeneous non-stationarity; bi = 0 for all *It_stat* is the CIPS statistic and CV the critical value associated with the various test stats, which precede them. When a critical probability is greater than the critical value, then the null hypothesis is not rejected and vice versa

Source(s): Authors

in the panel. With all p -values equal to 0, the alternative hypothesis of cross-sectional dependence is accepted. Our results show strong evidence for cross-sectional dependence when following Pesaran (2007), it is therefore rational to proceed with the second-generation stationarity tests. The results of the stationarity tests presented in Table 3 show that all the variables are stationary in level at a threshold point of 5%. These stationarity tests were carried out after verifying the problem of inter-individual dependencies. The estimates having revealed the characteristics of the variables, the VAR modeling can be used on the stationary series in level. These stationarity tests were carried out after verifying the problem of inter-individual dependencies.

In Table 4, we present the results of the PVAR model estimations, which indicate that the coefficients of all the variables are significant at a 1% threshold level. The results for the consumption of renewable energy showed a negative coefficient on the emissions of CO2. This result shows that renewable energies reduce CO2 emissions. A 1% drop in renewable energy consumption leads to a 3.41% drop in CO2. This result confirms previous work on reducing CO2 emissions (Dauda *et al.*, 2021; Namahoro *et al.*, 2021).

Regarding the link between the results and the existing literature, it has been opined by the latter that ICT stands as an important tool to combat environmental degradation (Ozcan and Apergis, 2018; Park *et al.*, 2018; Faisal *et al.*, 2020; Haldar and Sethi, 2021; Lin and Zhou, 2021). Indeed, the ICT variable measured by Internet penetration has a negative and significant effect on CO2 emissions; while the coefficient of the mobile phone variable is positive and significant on CO2 emissions. The spread of the Internet can be used to lessen the direful effect of globalization on environmental degradation linked to CO2 emissions.

The introduction of governance dynamics has been established in the existing literature to mitigate CO2 emissions (Wang and Dong, 2019; Asongu and Odhiambo, 2021a, b; Albitar *et al.*, 2023; Bildirci, 2022). In the present study, this is only confirmed from the governance composite indicator on renewable energy consumption on CO2 emissions and mobile telephony, while positive and significant on the Internet and gross domestic product. The governance composite indicator is considered a separate channel in its influence on

Variables	CO2	REC	Internet	Mobile	gdp	Inst
CO2	0.433*** (0.111)	-0.10454*** (0.0001)	3.368*** (0.983)	27.70*** (4.617)	-0.00922 (0.0114)	-0.944*** (0.250)
REC	-2.765*** (0.00067)	0.663*** (0.00032)	4.389 (0.000545)	-0.956*** (0.000436)	-8.8670*** (0.0078)	-3.016** (0.0012)
Internet	-0.00431* (0.00242)	0.00145** (0.0405)	0.804*** (0.0491)	0.468** (0.182)	0.000644 (0.000978)	0.0125 (0.00928)
Mobile	-0.000219 (0.000792)	-0.00239 (0.595)	0.0491*** (0.00970)	0.723*** (0.0635)	0.000514 (0.000325)	-0.00634** (0.00320)
gdp	-0.406*** (0.0463)	0.1086*** (0.0001)	-14.25*** (1.138)	-69.82*** (5.495)	-0.364*** (0.0292)	5.459*** (0.450)
Inst	0.0508** (0.0219)	-0.0099* (0.0625)	-0.241 (0.156)	7.480** (3.385)	0.0471** (0.0215)	0.362** (0.173)
Observations	817	817	817	817	817	817

Note(s): The numbers in parentheses are the standard errors: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.1$. The PVAR model is estimated by a fixed-effect GMM, taking into account the shifts leads to loss of data on the temporal dimension. The number of delays equal to 1 for the PVAR and 2 for the instruments; the number of instruments is equal to 1. To provide proof of the validity of the instruments, the specification test relating to the over-identification restrictions of Hansen (1982) was retained. Acceptance of the null hypothesis suggests the validity of the overidentifying restrictions. The results listed in the table show that the null hypothesis of the validity of the instruments is accepted at the 5% level

Source(s): Authors

Table 4.
Results of the panel
VAR model estimates

environmental degradation. In addition, economic growth favors this indicator, while it exerts the opposite effect on CO₂ emissions, REC and ICT variables.

Furthermore, there is evidence from many recent studies that economic growth has a positive and significant effect on CO₂ emissions (Adams and Nsiah, 2019; Muhammad, 2019). Our results confirm this hypothesis; every 1% increase in GDP is linked to 0.016% increase in CO₂ emissions.

The same is true for the consumption of renewable energy, where economic growth has a positive and significant effect. This is justified by the fact that African economies have experienced rapid globalization and strong economic trends such as industrial activities. The expansion of all these economic activities will result in emissions to the environment. However, the effect of economic growth on the technological variables (Internet and mobile) and on the institutional composite index is negative and significant. Indeed, there are significant technological problems due to innovation gaps, and most African states are usually far from technological frontiers. Furthermore, efficient regulation for a stable environment in African countries is still lagging behind.

To test the robustness of the VAR panel model, Abrigo and Love (2016) propose the model stability test. Thus, Figure A1 displays that all eigenvalues are within the unit circle and the panel VAR model is stable. In order to complete our analysis, the impulse response functions (IRF) make it possible to trace the dynamics of a variable following an impulse (shock) on another variable of the system. These simulations will be done over a more or less long period (10 periods). The technique of analysis of IRF, introduced in VAR modeling by Sims (1992), is a descriptive device representing the reaction of each variable to shocks in the different equations of the system. In this article, it will consist in evaluating the response of the CO₂ channel following a shock on the other variables of our model, taking into account the heterogeneity of this zone.

Figure A2 gives the estimate of the impulse response functions of the estimated PVAR model. It shows that mobile telephony responds negatively and quite significantly to a shock on CO₂ emissions from the first-four periods and thereafter a long-term equilibrium level. On the other hand, the consumption of renewable energy responds positively and quite significantly to a shock on CO₂ emissions before finding an equilibrium level. The institutional variables, the growth rate (GDP) and the internet do not react instantaneously to a shock on CO₂. The impulse response function shows that a positive shock of renewable energy consumption translates, six months later, by a decrease in the institutional composite variable, that of mobile telephony and a significant drop in CO₂. However, the energy shock leads to an increase in GDP and the internet.

The other response functions following the positive shocks of the institutional variables, the growth rate, the internet and mobile telephony result in a decrease and/or an increase in the variables.

Further, analysis of estimation results and impulse response functions shows that improving the environmental quality of African countries relies on the adoption of renewable energy as a subsidiary to traditional fossil fuel sources (Sarkodie and Adams, 2018). The adoption of this renewable energy should be a signal for policy makers to renounce the use of fossil fuels which alter the climate and accelerate Africa's transition towards renewable energy consumption. Achieving this objective is fundamentally based on the combination of technological efficiency via the internet and mobile telephony, and the reduction of carbon dioxide despite insufficient investment in research and development, telecommunications infrastructure and the transfer of technology. This combination refers to green technology and could facilitate the channel towards a sustainable market economy of African countries. However, robust institutional quality in African countries is mandatory for the preservation of the environment. In addition, regulations to promote the shift to renewable energy would go a long way to improving the environmental performance of African economies.

5. Conclusion, policy implications and research perspectives

This study complements the existing literature by assessing how sustainability and environmental protection can be promoted by significantly influencing the adoption and use of new information and communication technologies. The latter can act on the protection of the environment; radically transform methods or modes of production into clean techniques by saving energy and/or influencing institutions and governance. This article closes this gap by providing a number of theoretical mechanisms and empirical evidence for the diffusion of eco-friendly technologies and the interaction of the diffusion process with institutional quality using panel VAR modeling on 43 African countries. The results indicate that an attenuation of CO₂ emissions is generally linked with a greater speed of diffusion of digital technologies (mobile telephones and Internet). The results also suggest that robust institutional quality in African countries is mandatory for environmental preservation. In addition, regulations to stir the shift to renewable energy would go a long way to spur the environmental performance of African states. Our results also showed that economic growth has a positive and significant effect on CO₂ emissions.

The results of renewable energy consumption showed a negative coefficient on CO₂ emissions. This result shows that renewable energies reduce CO₂ emissions. Regarding the link between the results and the existing literature, it shows that Internet penetration has a negative and significant effect on CO₂ emissions while the coefficient of the mobile phone variable is positive and significant on CO₂ emissions. The spread of the Internet can be used to condense the dire effect of globalization on environmental degradation linked to CO₂ emissions. The introduction of governance dynamics has also been established in the existing literature to mitigate CO₂ emissions while positive and significant on the Internet and gross domestic product. The governance composite indicator is considered a separate channel in its influence on environmental degradation. In addition, economic growth favors this indicator, while it has the opposite effect on CO₂ emissions, renewable energy consumption and ICT variables. In what follows, the policy implications are discussed.

The main policy implication is that the introduction of governance dynamics has also been established in the existing literature to mitigate CO₂ emissions. The governance composite indicator (obtained through principal component analysis, PCA) has a negative impact on CO₂ emissions or reduces environmental degradation. This finding is relevant to policymakers as it highlights whether governance policies should be jointly implemented in tackling CO₂ emissions in Africa. It follows that the main governance policies should be simultaneously implemented, namely: (1) effective political governance in terms of the election and replacement of political leaders; (2) appropriate economic governance through the formulation and implementation of sound policies that deliver public goods and (3) strong institutional governance, particularly with regard to respect by citizens and the State of the institutions that govern the interactions between each other. Also, policy makers could potentially derive more benefits from the digitization process by adapting institutions and governance to the introduction of new technologies. The adoption of this renewable energy should be a signal for policy makers to renounce the use of fossil fuels which alter the climate and accelerate Africa's transition to renewable energy.

The underlying policy recommendations, especially as it pertains to the relevance of complementing good governance with green technology diffusion for environmental sustainability, should not exclusively be left for governments and policy makers to act upon. Accordingly, citizens can improve their daily carbon footprints by adopting information technologies that are friendlier to the environment as well as contribute to the improvement of political, economic and institutional governance in the country by actively participating in the relevant governance spheres to bring about better governance for environmental sustainability.

The results of this study obviously leave room for future research, especially when emphasizing on the potential country-level differences in institutions, governance, renewable

energy and other factors that may affect the development process and technology adoption. Therefore, the interaction between composite governance, green technology via mobile and Internet, renewable energy consumption and carbon emissions factors to assess whether the overall impact on carbon emissions is negative or not, is an interesting future research direction. Furthermore, given the established importance of renewables in mitigating CO₂ emissions, research and development dynamics linked to renewable energy could as well be considered as moderating variables in future studies.

References

- Abdulqadir, I.A. (2021), "Growth threshold-effect on renewable energy consumption in major oil-producing countries in sub-Saharan Africa: a dynamic panel threshold regression estimation", *International Journal of Energy Sector Management*, Vol. 15 No. 3, pp. 496-522, doi: [10.1108/IJESM-04-2020-0004](https://doi.org/10.1108/IJESM-04-2020-0004).
- Abdulqadir, I.A. (2022), "CO₂ emissions policy thresholds for renewable energy consumption on economic growth in OPEC member countries", *International Journal of Energy Sector Management*. doi: [10.1108/IJESM-08-2022-0013](https://doi.org/10.1108/IJESM-08-2022-0013).
- Abdulqadir, I.A. (2023), "Urbanization, renewable energy, and carbon dioxide emissions: a pathway to achieving sustainable development goals (SDGs) in sub-Saharan Africa", *International Journal of Energy Sector Management*. doi: [10.1108/IJESM-11-2022-0032](https://doi.org/10.1108/IJESM-11-2022-0032).
- Abid, M. (2016), "Impact of economic, financial, and institutional factors on CO₂ emissions: evidence from sub-Saharan Africa economies", *Utilities Policy*, Vol. 41, pp. 85-94.
- Abrego, M.R. and Love, I. (2016), "Estimation of panel vector autoregression in Stata", *The Stata Journal*, Vol. 16 No. 3, pp. 778-804.
- Acheampong, A.O., Adams, S. and Boateng, E. (2019), "Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa?", *Science of the Total Environment*, Vol. 677, pp. 436-446.
- Adams, S. and Nsiah, C. (2019), "Reducing carbon dioxide emissions; Does renewable energy matter?", *Science of the Total Environment*, Vol. 693, 133288.
- Adams, S., Acheampong and Alex, O. (2019), "Reducing carbon emissions: the role of renewable energy and democracy", *Journal of Cleaner Production*, Vol. 240, 118245, doi: [10.1016/j.jclepro.2019.118245](https://doi.org/10.1016/j.jclepro.2019.118245).
- Adebayo, T.S. and Kirikkaleli, D. (2021), "Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools", *Environment, Development and Sustainability*, Vol. 23 No. 11, pp. 16057-16082.
- Adekoya, O.B., Olabode, J.K. and Rafi, S.K. (2021), "Renewable energy consumption, carbon emissions and human development: empirical comparison of the trajectories of world regions", *Renew. Energy*, Vol. 179, pp. 1836-1848, doi: [10.1016/j.renene.2021.08.019](https://doi.org/10.1016/j.renene.2021.08.019).
- Alam, S., Fatima, A. and Butt, M.S. (2007), "Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation", *Journal of Asian Economics*, Vol. 18 No. 5, pp. 825-837.
- Albitar, K., Borgi, H., Khan, M. and Zahra, A. (2023), "Business environmental innovation and CO₂ emissions: the moderating role of environmental governance", *Business Strategy and the Environment*, Vol. 32 No. 4, pp. 1996-2007.
- Almeida, T.A.D.N. and García-Sánchez, I.M. (2017), "Socio-political and economic elements to explain the environmental performance of countries", *Environmental Science and Pollution Research*, Vol. 24, pp. 3006-3026.
- Asongu, S.A. (2018), "CO₂ emission thresholds for inclusive human development in sub-Saharan Africa", *Environmental Science and Pollution Research*, Vol. 25, pp. 26005-26019.

- Asongu, S.A. and Odhiambo, N.M. (2021a), "Enhancing governance for environmental sustainability in sub-Saharan Africa", *Energy Exploration and Exploitation*, Vol. 39 No. 1, pp. 444-463.
- Asongu, S.A. and Odhiambo, N.M. (2021b), "Inequality, finance and renewable energy consumption in Sub-Saharan Africa", *Renewable Energy*, Vol. 165, pp. 678-688.
- Asongu, S., El Montasser, G. and Toumi, H. (2016), "Testing the relationships between energy consumption, CO₂ emissions, and economic growth in 24 African countries: a panel ARDL approach", *Environmental Science and Pollution Research*, Vol. 23, pp. 6563-6573.
- Asongu, S.A., Le Roux, S. and Biekpe, N. (2018), "Enhancing ICT for environmental sustainability in sub-Saharan Africa", *Technological Forecasting and Social Change*, Vol. 127, pp. 209-216.
- Asongu, S.A., Agboola, M.O., Alola, A.A. and Bekun, F.V. (2020), "The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa", *Science of the Total Environment*, Vol. 712, 136376.
- Azam, M., Liu, L. and Ahmad, N. (2021a), "Impact of institutional quality on environment and energy consumption: evidence from developing world", *Environment, Development and Sustainability* Vol. 23 No. 2, pp. 1646-1667, doi: [10.1007/s10668-020-00644-](https://doi.org/10.1007/s10668-020-00644-).
- Azam, M., Hunjra, A.I., Bouri, E., Tan, Y. and Al-Faryan, M.A.S. (2021b), "Impact of institutional quality on sustainable development: evidence from developing countries", *Journal of Environmental Management*, Vol. 298, 113465.
- Bildirici, M. (2022), "The impacts of governance on environmental pollution in some countries of Middle East and sub-Saharan Africa: the evidence from panel quantile regression and causality", *Environmental Science and Pollution Research*, Vol. 29 No. 12, pp. 17382-17393.
- Cheng, C., Ren, X., Dong, K., Dong, X. and Wang, Z. (2021), "How does technological innovation mitigate CO₂ emissions in OECD countries? Heterogeneous analysis using panel quantile regression", *Journal of Environmental Management*, Vol. 280, 111818.
- Comin, D. and Hobijn, B. (2004), "Cross-country technology adoption: making the theories face the facts", *Journal of Monetary Economics*, Vol. 51 No. 1, pp. 39-83.
- Comin, D., Easterly, W. and Gong, E. (2010), "Was the wealth of nations determined in 1000 BC?", *American Economic Journal: Macroeconomics*, Vol. 2 No. 3, pp. 65-97.
- Dauda, L., Long, X., Mensah, C.N., Salman, M., Boamah, K.B., Ampon-Wireko, S. and Dogbe, C.S.K. (2021), "Innovation, trade openness and CO₂ emissions in selected countries in Africa", *Journal of Cleaner Production*, Vol. 281, 125143.
- De La Peña, L., Guo, R., Cao, X., Ni, X. and Zhang, W. (2022), "Accelerating the energy transition to achieve carbon neutrality", *Resources, Conservation and Recycling*, Vol. 177, 105957.
- Du, K., Li, P. and Yan, Z. (2019), "Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data", *Technological Forecasting and Social Change*, Vol. 146, pp. 297-303.
- Edquist, C. (Ed.) (1997), *Systems of Innovation: Technologies, Institutions, and Organizations*, Psychology Press, Routledge.
- Egbetokun, S., Osabuohien, E., Akinbobola, T., Onanuga, O.T., Gershon, O. and Okafor, V. (2020), "Environmental pollution, economic growth and institutional quality: exploring the nexus in Nigeria", *Management of Environmental Quality: An International Journal*, Vol. 31 No. 1, pp. 18-31.
- Fagbohunbe, M.O., Komolafe, A.O. and Okere, U.V. (2019), "Renewable hydrogen anaerobic fermentation technology: problems and potentials", *Renewable and Sustainable Energy Reviews*, Vol. 114, 109340.
- Faisal, A.A., Abdul-Kareem, M.B., Mohammed, A.K., Naushad, M., Ghfar, A.A. and Ahamad, T. (2020), "Humic acid coated sand as a novel sorbent in permeable reactive barrier for environmental remediation of groundwater polluted with copper and cadmium ions", *Journal of Water Process Engineering*, Vol. 36, 101373.

- Fakher, H.A., Ahmed, Z., Acheampong, A.O. and Nathaniel, S.P. (2023), "Renewable energy, non-renewable energy, and environmental quality nexus: an investigation of the N-shaped Environmental Kuznets Curve based on six environmental indicators", *Energy*, Vol. 263, 125660.
- Haldar, A. and Sethi, N. (2021), "Effect of institutional quality and renewable energy consumption on CO2 emissions— an empirical investigation for developing countries", *Environmental Science and Pollution Research*, Vol. 28 No. 12, pp. 15485-15503.
- Halkos, G.E. and Tzeremes, N.G. (2013), "Carbon dioxide emissions and governance: a nonparametric analysis for the G-20", *Energy Economics*, Vol. 40, pp. 110-118.
- Hansen, L.P. (1982), "Large sample properties of generalized method of moments estimators", *Econometrica: Journal of the Econometric Society*, Vol. 50 No. 4, pp. 1029-1054.
- Hosseini, H.M. and Kaneko, S. (2013), "Can environmental quality spread through institutions?", *Energy Policy*, Vol. 56, pp. 312-321, doi: [10.1016/j.enpol.2012.12.067](https://doi.org/10.1016/j.enpol.2012.12.067).
- Hottenrott, H., Rexhäuser, S. and Veugelers, R. (2016), "Organisational change and the productivity effects of green technology adoption", *Resource and Energy Economics*, Vol. 43, pp. 172-194.
- Hurlin, C. and Mignon, V. (2005), "Une synthèse des tests de racine unitaire sur données de panel", *Economie Prevision*, Vol. 169170171 No. 3, pp. 253-294.
- Ibrahiem, D.M. (2020), "Do technological innovations and financial development improve environmental quality in Egypt?", *Environmental Science and Pollution Research*, Vol. 27 No. 10, pp. 10869-10881.
- Im, K.S., Pesaran, M.H. and Shin, Y. (2003), "Testing for unit roots in heterogeneous panels", *Journal of Econometrics*, Vol. 115 No. 1, pp. 53-74.
- Inglese-Lotz, R. and Dogan, E. (2018), "The role of renewable versus non-renewable energy to the level of CO2 emissions a panel analysis of sub-Saharan Africa's Big 10 electricity generators", *Renewable Energy*, Vol. 123, pp. 36-43.
- Karekezi, S. (2002), "Renewables in Africa—meeting the energy needs of the poor", *Energy Policy*, Vol. 30 Nos 11-12, pp. 1059-1069.
- Karekezi, S., Kithyoma, W. and Initiative, E. (2003), "Renewable energy development", *workshop on African Energy Experts on Operationalizing the NEPAD Energy Initiative*, pp. 2-4, June.
- Kenner, D. and Heede, R. (2021), "White knights, or horsemen of the apocalypse? Prospects for Big Oil to align emissions with a 1.5° C pathway", *Energy Research and Social Science*, Vol. 79, 102049.
- Khattak, S.I., Ahmad, M., Khan, Z.U. and Khan, A. (2020), "Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the BRICS economies", *Environmental Science and Pollution Research*, Vol. 27 No. 12, pp. 13866-13881.
- Ko, Y.C., Zigan, K. and Liu, Y.L. (2021), "Carbon capture and storage in South Africa: a technological innovation system with a political economy focus", *Technological Forecasting and Social Change*, Vol. 166, 120633.
- Lameira, V.D.J., Ness, W.L., Jr, Harris, J.E. and Pereira, R.G.E. (2016), "CO2 emissions, energy use and country governance", *International Journal of Industrial and Systems Engineering*, Vol. 24 No. 2, pp. 241-256.
- Lee, J.W. and Brahmasrene, T. (2014), "ICT, CO2 emissions and economic growth: evidence from a panel of ASEAN", *Global Economic Review*, Vol. 43 No. 2, pp. 93-109.
- Leitao, A. (2016), "Corruption and the environment", *Journal of Socialomics*, Vol. 5, pp. 2-5, doi: [10.4172/2167-0358.1000173](https://doi.org/10.4172/2167-0358.1000173).
- Lema, R. and Lema, A. (2012), "Transfert de technologie? La montée en puissance de la Chine et de l'Inde dans les secteurs des technologies vertes", *Innovation et Développement*, Vol. 2 No. 1, pp. 23-44.
- Levin, A., Lin, C.F. and Chu, C.S.J. (2002), "Unit root tests in panel data: asymptotic and finite-sample properties", *Journal of Econometrics*, Vol. 108 No. 1, pp. 1-24.

- Lin, B. and Zhou, Y. (2021), "Does the Internet development affect energy and carbon emission performance?", *Sustainable Production and Consumption*, Vol. 28, pp. 1-10, doi: [10.1016/j.spc.2021.03.016](https://doi.org/10.1016/j.spc.2021.03.016).
- Love, I. and Zicchino, L. (2006), "Financial development and dynamic investment behavior: evidence from panel VAR", *The Quarterly Review of Economics and Finance*, Vol. 46 No. 2, pp. 190-210.
- Majeed, H. and Svendsen, H.F. (2018), "Characterization of aerosol emissions from CO2 capture plants treating various power plant and industrial flue gases", *International Journal of Greenhouse Gas Control*, Vol. 74, pp. 282-295.
- Muhammad, B. (2019), "Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries", *Energy*, Vol. 179, pp. 232-245.
- Namahoro, J.P., Wu, Q., Zhou, N. and Xue, S. (2021), "Impact of energy intensity, renewable energy, and economic growth on CO2 emissions: evidence from Africa across regions and income levels", *Renewable and Sustainable Energy Reviews*, Vol. 147, 11233.
- North, D.C. (1991), "Institutions", *Journal of Economic Perspectives*, Vol. 5 No. 1, pp. 97-112.
- Nwulu, N.I., Oroja, S. and Ilkan, M. (2011), "Évaluation du crédit à l'aide de schémas informatiques souples : une comparaison entre les machines à vecteurs de support et les réseaux de neurones artificiels", *Dans Digital Enterprise and Information Systems: International Conference, DEIS 2011, Londres, Royaume-Uni, 20-22 juillet 2011*, Springer Berlin Heidelberg, pp. 275-286, Actes.
- N'dri, L.M., Islam, M. and Kakinaka, M. (2021), "ICT and environmental sustainability: any differences in developing countries?", *Journal of Cleaner Production*, Vol. 297, 126642.
- Obobisa, E.S. (2022), "Achieving 1.5 C and net-zero emissions target: the role of renewable energy and financial development", *Renewable Energy*, Vol. 188, pp. 967-985.
- Obobisa, E.S., Chen, H. and Mensah, I.A. (2022), "The impact of green technological innovation and institutional quality on CO2 emissions in African countries", *Technological Forecasting and Social Change*, Vol. 180, 121670.
- Ozcan, B., Apergis, N. and Shahbaz, M. (2018), "A revisit of the environmental Kuznets curve hypothesis for Turkey: new evidence from bootstrap rolling window causality", *Environmental Science and Pollution Research*, Vol. 25, pp. 32381-32394.
- Park, Y., Meng, F. and Baloch, M.A. (2018), "The effect of ICT, financial development, growth, and trade openness on CO2 emissions: an empirical analysis", *Environmental Science and Pollution Research*, Vol. 25, pp. 30708-30719, doi: [10.1007/s11356-018-3108-6](https://doi.org/10.1007/s11356-018-3108-6).
- Pesaran, M.H. (2004), "General diagnostic tests for cross-sectional dependence in panels", *Empirical Economics*, Vol. 60 No. 1, pp. 13-50.
- Pesaran, M.H. (2007), "A simple panel unit root test in the presence of cross-section dependence", *Journal of Applied Econometrics*, Vol. 22 No. 2, pp. 265-312.
- Pesaran, M.H., Ullah, A. and Yamagata, T. (2008), "A bias-adjusted LM test of error cross-section independence", *The Econometrics Journal*, Vol. 11 No. 1, pp. 105-127.
- Raheem, I.D., Tiwari, A.K. and Balsalobre-Lorente, D. (2020), "The role of ICT and financial development in CO2 emissions and economic growth", *Environmental Science and Pollution Research*, Vol. 27 No. 2, pp. 1912-1922.
- Salahuddin, M., Alam, K. and Ozturk, I. (2016), "Les effets de l'utilisation d'Internet et de la croissance économique sur les émissions de CO2 dans les pays de l'OCDE: une enquête par panel", *Revue des énergies renouvelables et durables*, Vol. 62, pp. 1226-1235.
- Salman, M., Long, X., Dauda, L. and Mensah, C.N. (2019), "The impact of institutional quality on economic growth and carbon emissions: evidence from Indonesia, South Korea and Thailand", *Journal of Cleaner Production*, Vol. 241 No. 118331, pp. 0959-6526, doi: [10.1016/j.jclepro.2019.118331](https://doi.org/10.1016/j.jclepro.2019.118331).
- Samimi, A.J., Ahmadpour, M. and Ghaderi, S. (2012), "Governance and environmental degradation in MENA region", *Procedia-Social and Behavioral Sciences*, Vol. 62, pp. 503-507.

- Sarkodie, S.A. and Adams, S. (2018), "Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa", *Science of the Total Environment*, Vol. 643, pp. 1590-1601.
- Sims, C.A. (1992), "Interpreting the macroeconomic time series facts: the effects of monetary policy", *European Economic Review*, Vol. 36 No. 5, pp. 975-1000.
- Su, C.W., Yuan, X., Tao, R. and Umar, M. (2021a), "Can new energy vehicles help to achieve carbon neutrality targets?", *Journal of Environmental Management*, Vol. 297, 113348.
- Su, C.W., Xie, Y., Shahab, S., Faisal, C.M.N., Hafeez, M. et Qamri, G.M. (2021b), "Vers un développement durable: rôle de l'innovation technologique, de l'adoption de la technologie et des émissions de CO₂ pour les BRICS", *Revue internationale de recherche environnementale et de santé publique*, Vol. 18 No. 1, p. 277.
- Sun, H., Edziah, B.K., Sun, C. and Kporsu, A.K. (2019), "Institutional quality, green innovation and energy efficiency", *Energy Policy*, Vol. 135, 111002.
- Tamazian, A. and Rao, B.B. (2010), "Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies", *Energy Economics*, Vol. 32 No. 1, pp. 137-145.
- Tchamy, V.S. (2019), "The role of information sharing in modulating the effect of financial access on inequality", *Journal of African Business*, Vol. 20 No. 3, pp. 317-338.
- Teng, J.Z., Khan, M.K., Khan, M.I., Chishti, M.Z. and Khan, M.O. (2021), "Effect of foreign direct investment on CO₂ emission with the role of globalization, institutional quality with pooled mean group panel ARDL", *Environmental Science and Pollution Research*, Vol. 28, pp. 5271-5282.
- Traoré, A., Ndour, C.T. and Asongu, S.A. (2023), "Promoting environmental sustainability in Africa: evidence from governance synergy", *Climate and Development*, Forthcoming.
- Uluçak, R. (2021), "Renewable energy, technological innovation and the environment: a novel dynamic auto-regressive distributive lag simulation", *Renewable and Sustainable Energy Reviews*, Vol. 150, 111433.
- Wang, J. and Dong, K. (2019), "What drives environmental degradation? Evidence from 14 Sub-Saharan African countries", *Science of the Total Environment*, Vol. 656, pp. 165-173.
- Wang, Z., Zhang, B. and Wang, B. (2018), "The moderating role of corruption between economic growth and CO₂ emissions: evidence from BRICS economies", *Energy*, Vol. 148, pp. 506-513.
- Wang, M., Li, Y., Li, J. and Wang, Z. (2021), "L'innovation de processus vert, l'innovation de produit vert et ses voies d'amélioration de la performance économique: une enquête et un modèle structurel", *Journal of Environmental Management*, Vol. 297, 113282, doi: [10.1016/j.jenvman.2021.113282](https://doi.org/10.1016/j.jenvman.2021.113282).
- World Bank (2022), *World Bank Global Electrification Database*, World Bank, Washington, DC. available at: <https://databank.worldbank.org/source/world-development-indicators> (accessed 17 June 2023).
- Xie, Q., Adebayo, T.S., Irfan, M. and Altuntaş, M. (2022), "Race to environmental sustainability: can renewable energy consumption and technological innovation sustain the strides for China?", *Renewable Energy*, Vol. 197, pp. 320-330.
- Young, H.P. (2010), "Innovation diffusion in heterogeneous populations: contagion, social influence, and social learning", *American Economic Review*, Vol. 99 No. 5, pp. 1899-1924.
- Youssef, A.B., Boubaker, S. and Omri, A. (2018), "Entrepreneurship and sustainability: the need for innovative and institutional solutions", *Technological Forecasting and Social Change*, Vol. 129, pp. 232-241.
- Yuan, X., Su, C.W., Umar, M., Shao, X. and Lobonţ, O.R. (2022), "The race to zero emissions: can renewable energy be the path to carbon neutrality?", *Journal of Environmental Management*, Vol. 308, 114648.
- Zhang, Y., Zhao, W. and Ge, J. (2016), "Institutional duality and political strategies of foreign-invested firms in an emerging economy", *Journal of World Business*, Vol. 51 No. 3, pp. 451-462.

Further reading

- Awan, A., Alnour, M., Jahanger, A. and Onwe, J.C. (2022), "Do technological innovation and urbanization mitigate carbon dioxide emissions from the transport sector?", *Technology in Society*, Vol. 71, 102128.
- Nikolaidis, P., Chatzis, S. and Poullikkas, A. (2019), "Renewable energy integration through optimal unit commitment and electricity storage in weak power networks", *International Journal of Sustainable Energy*, Vol. 38 No. 4, pp. 398-414.
- Njoh, A.J. (2021), "Renewable energy as a determinant of inter-country differentials in CO2 emissions in Africa", *Renewable Energy*, Vol. 172, pp. 1225-1232, doi: [10.1016/j.renene.2021.03.096](https://doi.org/10.1016/j.renene.2021.03.096).

Appendices

Algeria	Republic Congo	Libya	Senegal
Angola	Ivory Coast	Madagascar	Seychelles
			Sierra Leone
Benin	Egypt	Mali	South Africa
Botswana	Eritrea	Mauritania	Sudan
	Ethiopia		
Burkina Faso	Gabon	Mauritius	Tanzania
Burundi	Gambia	Morocco	Togo
Cameroon	Ghana	Mozambique	Tunisia
Cape Verde	Guinea	Namibia	Zambia
Comoros	Guinea-Bissau	Niger	Zimbabwe
Congo Democratic	Kenya	Nigeria	
	Lesotho	Rwanda	

Note(s): WDI, World Bank Development Indicators

Source(s): Authors' compilation

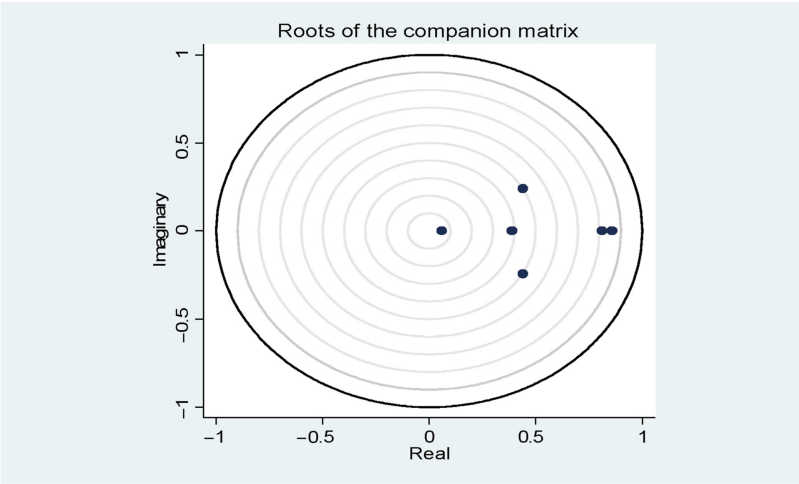
Table A1.
The list of countries

Signs	Definitions of variables (measurements)	Sources
CO2	carbon dioxide emissions (metric tons per capita)	World Bank (WDI)
REC	Sum of Hydro, wind, Solar and Nuclear, Energy usage (million tons oil equivalent)	
Inst	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 A3)	authors
PS	Political stability and absence of violence/terrorism	World Bank (WGI)
VA	Voice democratic expression and accountability (EDemocray 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)	
Mobile	Mobile phone subscriptions (per 100 people)	World Bank (WDI)
Internet	Internet penetration (per 100 people)	World Bank (WDI)
Gdp	Real gross domestic product per capita (GDP per capita) in US dollars	World Bank (WDI)

Table A2.
Definitions and sources
of variables

Source(s): Authors

Figure A1.
Model stability test in
VAR panel



Source(s): Authors

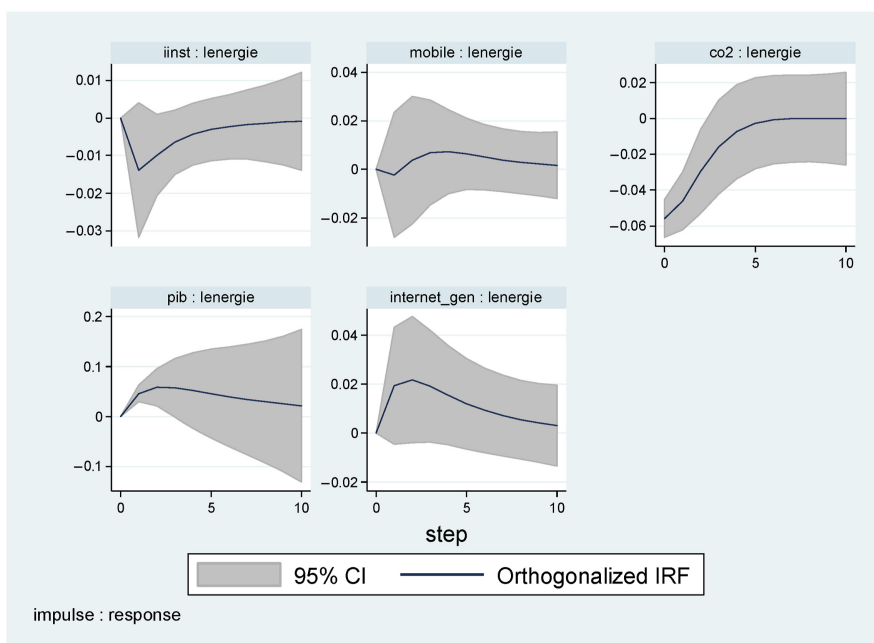
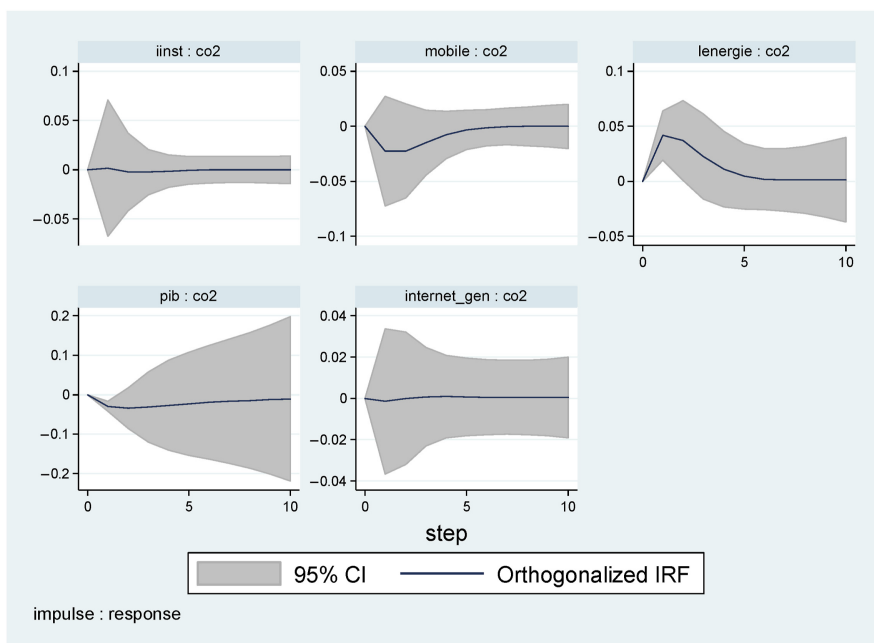


Figure A2.
The response functions
of the different
variables

(continued)

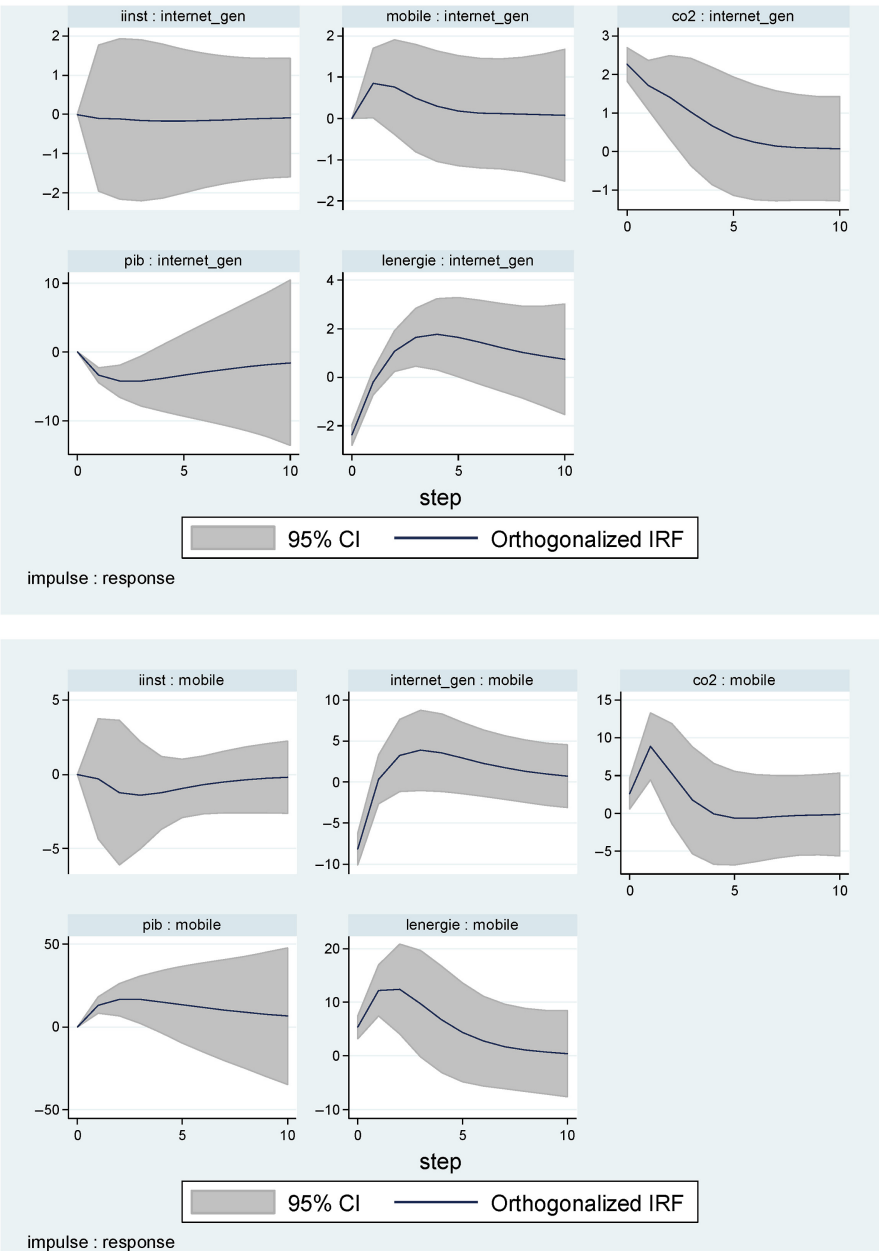
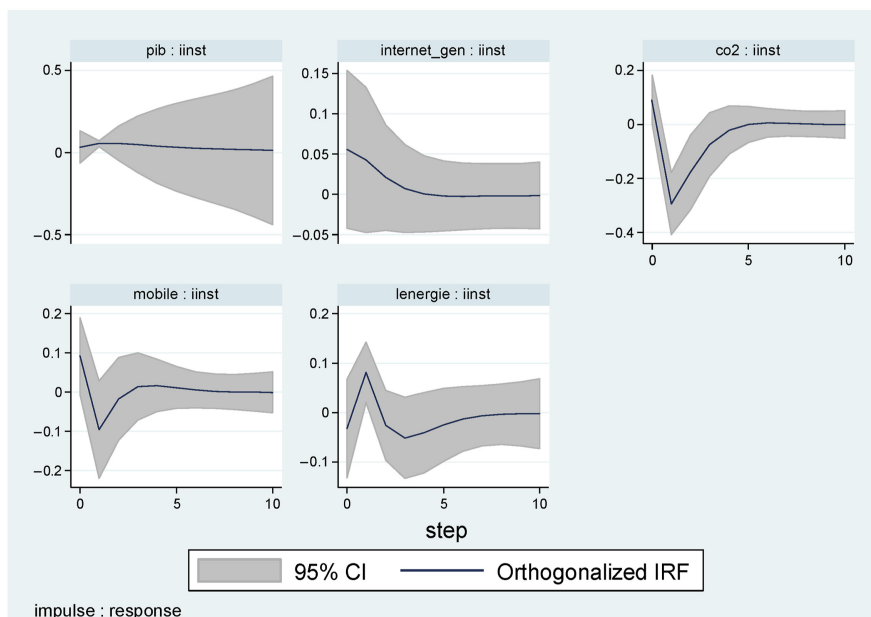
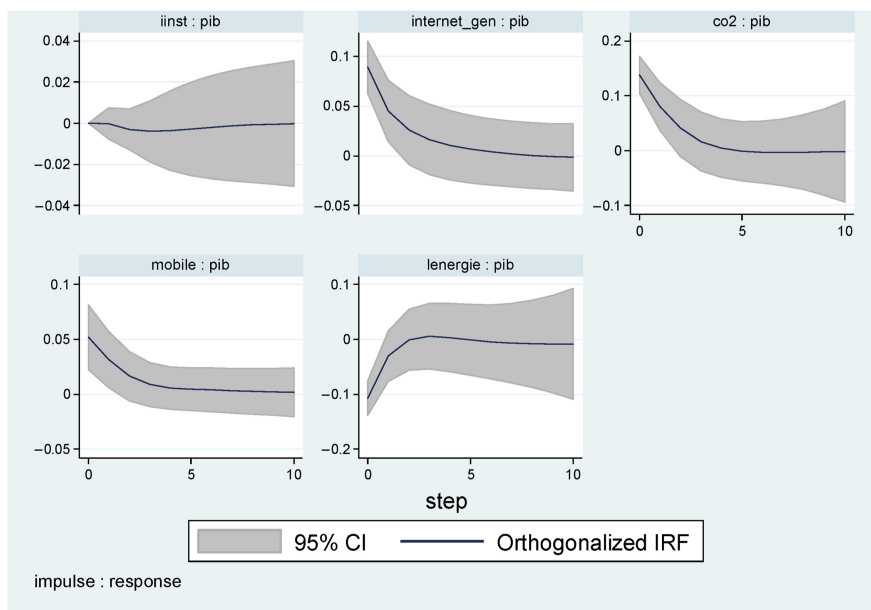


Figure A2

(continued)



Source(s): Authors

Figure A2

MEQ
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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

484

Note(s): 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

Source(s): Authors' calculations

Table A3.

Principal Component Analysis (PCA)

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