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

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Received 18 May 2023
Revised 5 July 2023
Accepted 27 August 2023

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

JEL Classification — C52, 031, 033, 043, 055

The authors are indebted to the editor and reviewers for constructive comments.

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 CO_2 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 CO_2 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 CO_2 and found that a 1% increase in structural change and economic growth leads to an increase in CO_2 of 1.600 and 0.819%.

Furthermore, over a sample of 23 most industrialized countries, Comin and Hoijin (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 (Fagbohungbe *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 and 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:

$$Y_{it} = A_1 Y_{it-1} + A_2 Y_{it-2} + A_3 Y_{it-3} + \ldots A_p Y_{it-p} + BX_{it} + u_{it} + e_{it} \quad (1)$$

$$i \in \{1, 2, \ldots, N\}, t \in \{1, 2, \ldots, T_i\}$$

where Y_{it} is a vector $(1 * k)$ of endogenous variables; X_{it} is a vector $(1 * 1)$ exogenous variables; u_i and e_{it} are vectors $(1 * k)$ 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:

$$\begin{bmatrix} 1 a_{12} a_{13} a_{14} a_{15} a_{16} \\ a_{21}\ 2\, a_{23} a_{24} a_{25} a_{26} \\ a_{31} a_{32} 3 a_{34} a_{35} a_{36} \\ a_{41} a_{42} a_{43} 4 a_{45} a_{46} \\ a_{51} a_{52} a_{53} a_{54} 5\, a_{56} \\ a_{61} a_{62} a_{63} a_{64} a_{65} 6 \end{bmatrix} \begin{bmatrix} C02_{i,t} \\ REC_{i,t} \\ Internet_{i,t} \\ Mobile_{i,t} \\ gdp_{i,t} \\ Inst_{i,t} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \\ a_{30} \\ a_{40} \\ a_{50} \\ a_{60} \end{bmatrix} + \begin{bmatrix} L_{11}L_{12}L_{13}L_{14}L_{15}L_{16} \\ L_{21}L_{22}L_{23}L_{24}L_{25}L_{26} \\ L_{31}L_{32}L_{33}L_{34}L_{35}L_{36} \\ L_{41}L_{42}L_{43}L_{44}L_{45}L_{46} \\ L_{51}L_{52}L_{53}L_{54}L_{55}L_{56} \\ L_{61}L_{62}L_{63}L_{64}L_{65}L_{66} \end{bmatrix} \begin{bmatrix} CO2_{i,t-p} \\ REC_{i,t-p} \\ Internet_{i,t-p} \\ Mobile_{i,t-p} \\ gdp_{i,t-p} \\ Inst_{i,t-p} \end{bmatrix} + \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \\ \mu_6 \end{bmatrix} \quad (2)$$

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:

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

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 $E[\overline{\overline{Y}*'}Z] = kp + l$

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

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 1.
Descriptive statistics

Variable	CD-test	*p*-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 ~ N(0.1) and a *p*-value close to zero indicate data that are correlated between panel individuals, CD signifies the cross-sectional dependence statistic
Source(s): Authors

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

Tests carried out on the series in level				
Tests	*t*-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 I.t_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

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

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; Bildirici, 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***	−0.10454***	3.368***	27.70***	−0.00922	−0.944***
	(0.111)	(0.0001)	(0.983)	(4.617)	(0.0114)	(0.250)
REC	−2.765***	0.663***	4.389	−0.956***	−8.8670***	−3.016**
	(0.00067)	(0.00032)	(0.000545)	(0.000436)	(0.0078)	(0.0012)
Internet	−0.00431*	0.00145**	0.804***	0.468**	0.000644	0.0125
	(0.00242)	(0.0405)	(0.0491)	(0.182)	(0.000978)	(0.00928)
Mobile	−0.000219	−0.00239	0.0491***	0.723***	0.000514	−0.00634**
	(0.000792)	(0.595)	(0.00970)	(0.0635)	(0.000325)	(0.00320)
gdp	−0.406***	0.1086***	−14.25***	−69.82***	−0.364***	5.459***
	(0.0463)	(0.0001)	(1.138)	(5.495)	(0.0292)	(0.450)
Inst	0.0508**	−0.0099*	−0.241	7.480**	0.0471**	0.362**
	(0.0219)	(0.0625)	(0.156)	(3.385)	(0.0215)	(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 CO_2 emissions, REC and ICT variables.

Furthermore, there is evidence from many recent studies that economic growth has a positive and significant effect on CO_2 emissions (Adams and Nsiah, 2019; Muhammad, 2019). Our results confirm this hypothesis; every 1% increase in GDP is linked to 0.016% increase in CO_2 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 CO_2 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 CO_2 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 CO_2 emissions before finding an equilibrium level. The institutional variables, the growth rate (GDP) and the internet do not react instantaneously to a shock on CO_2. 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 CO_2. 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 CO_2 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 CO_2 emissions.

The results of renewable energy consumption showed a negative coefficient on CO_2 emissions. This result shows that renewable energies reduce CO_2 emissions. Regarding the link between the results and the existing literature, it shows that Internet penetration has a negative and significant effect on CO_2 emissions while the coefficient of the mobile phone variable is positive and significant on CO_2 emissions. The spread of the Internet can be used to condense the dire effect of globalization on environmental degradation linked to CO_2 emissions. The introduction of governance dynamics has also been established in the existing literature to mitigate CO_2 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 CO_2 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 CO_2 emissions. The governance composite indicator (obtained through principal component analysis, PCA) has a negative impact on CO_2 emissions or reduces environmental degradation. This finding is relevant to policymakers as it highlights whether governance policies should be jointly implemented in tackling CO_2 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.

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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	Mozambia	Tunisia
Cape Verde	Guinea	Namibia	Zambia
Comoros	Guinea-Bissau	Niger	Zimbabwe
Congo Democratic	Kenya	Nigeria	
	Lesotho	Rwanda	

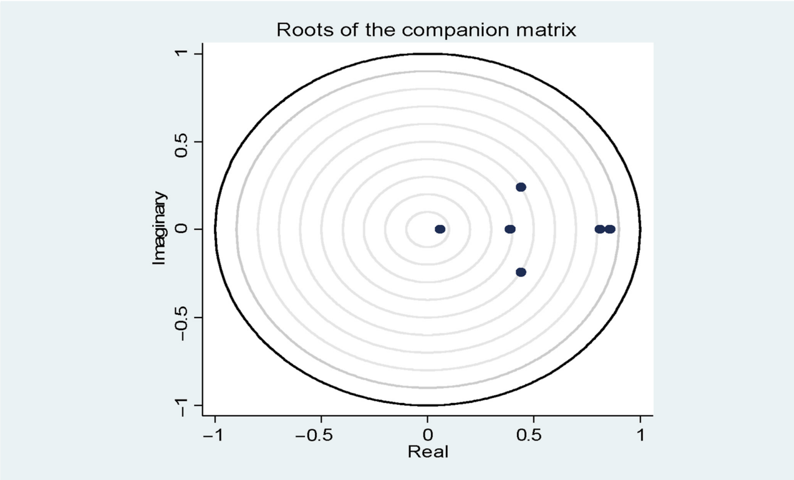
Note(s): WDI, World Bank Development Indicators
Source(s): Authors' compilation

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
VA	Voice democratic expression and accountability (EDemocray Composite Governance Index)	(WGI)
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
Internet	Internet penetration (per 100 people)	(WDI)
Gdp	Real gross domestic product per capita (GDP per capita) in US dollars	World Bank (WDI)

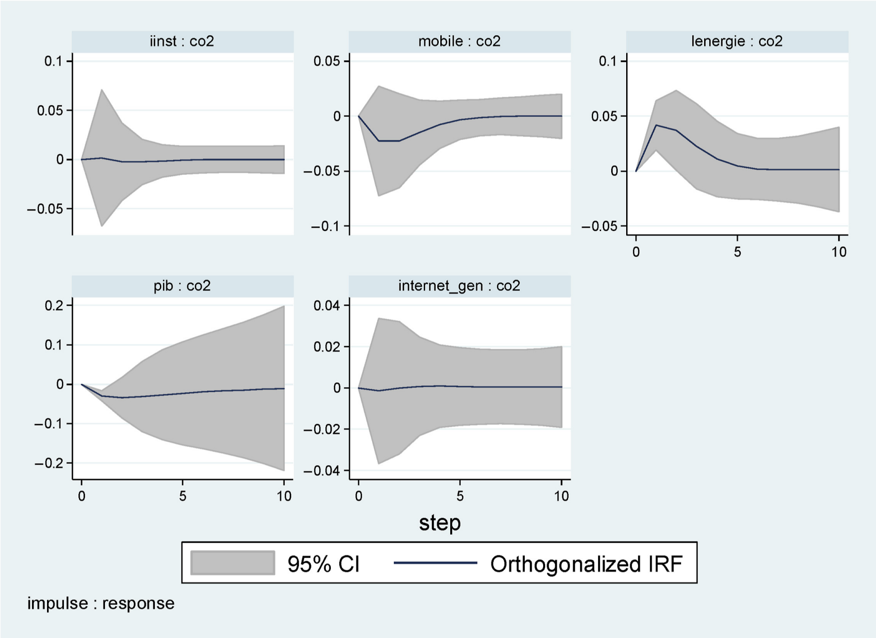
Source(s): Authors

Table A2. Definitions and sources of variables



Source(s): Authors

Figure A1.
Model stability test in VAR panel



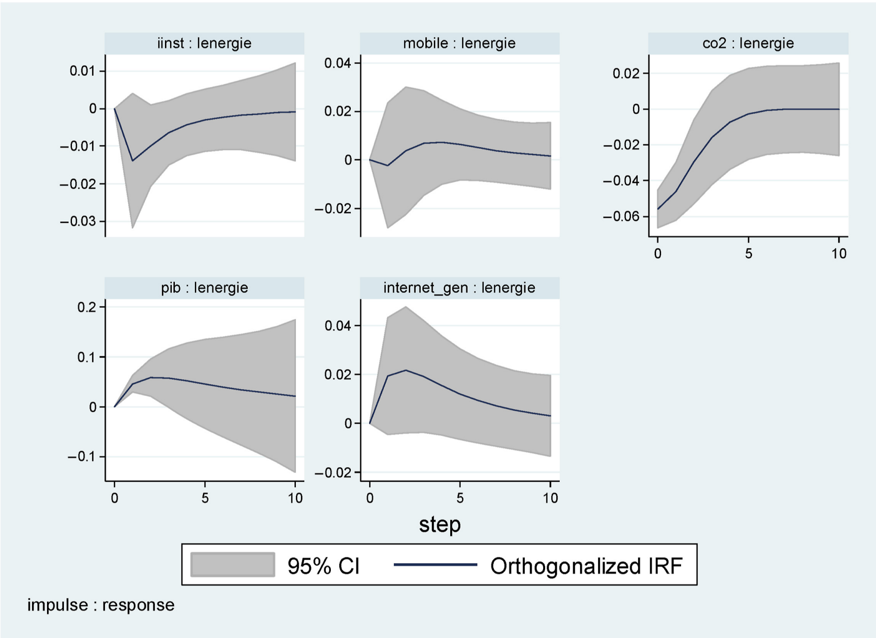
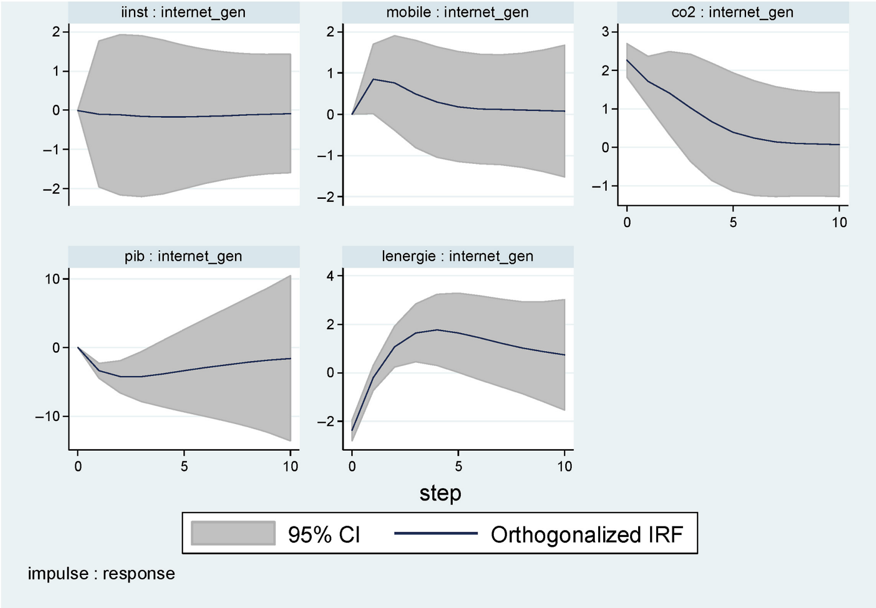


Figure A2.
The response functions of the different variables

(*continued*)



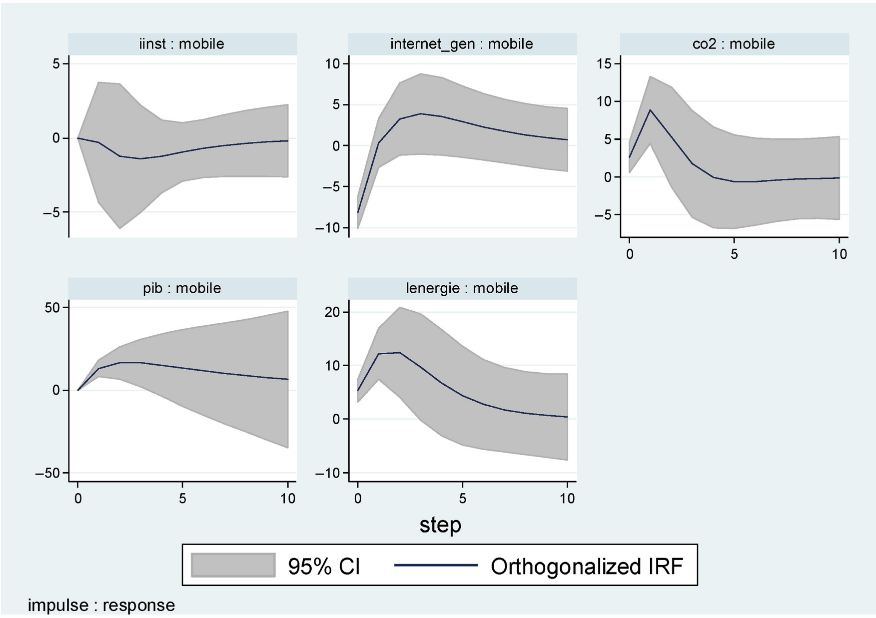
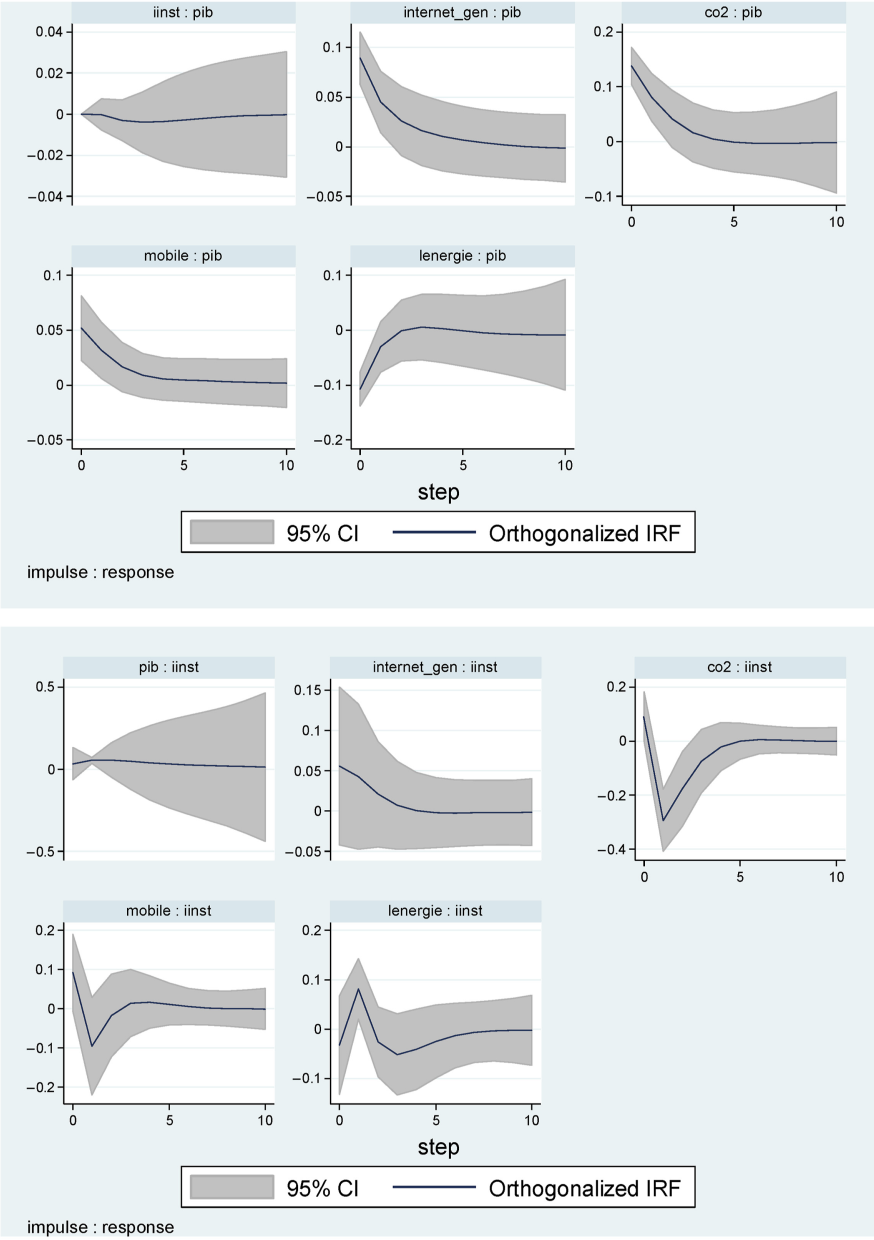


Figure A2

(*continued*)



Source(s): Authors

Figure A2

Table A3.
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

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

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