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Article

The moderating role of ICT on the relationship between foreign direct investment and the quality of environment in selected African countries

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GENERAL & APPLIED ECONOMICS | RESEARCH ARTICLE

The moderating role of ICT on the relationship between foreign direct investment and the quality of environment in selected African countries

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Aminu Hassan Jakada¹*, Suraya Mahmood², Umar Ahmad Ali³ and Danmaraya Ismail Aliyu⁴

Abstract: This empirical study examines the role of information and communication technology (ICT) in the relationship between FDI and environmental quality for six leading African economies from 1970 to 2020. The second-generation tests are used to determine the stationarity level of the variables. Furthermore, the Westerlund panel cointegration test confirms cointegration among the variables. For long-run association, CS-ARDL, which resolved the consequences of heterogeneity and cross-sectional dependency is used. The results of the study reveal that ICT, FDI, economic growth, and financial development degrade environmental quality. The interacting effect of ICT and FDI (ICT*FDI) leads to escalation of CO₂ emissions thereby deteriorating the quality of the environment. The study recommends that African countries should promote FDI to support the inflow of green technologies to enhance environmental quality. The implementation of environmental quality in the long term and conserve resources for future generation.

Subjects: Environmental Economics; Economics; Finance

Keywords: ICT; FDI; economic growth; environmental quality

1. Introduction

Increasing environmental deterioration requires policymakers to place a greater emphasis on incorporating sustainability into economic growth plans. The current Sustainable Development Goals (SDG) report, that is Agenda 2030, has connected the issue of growing climate disasters throughout the world to the global economic growth trend. Climate change, global warming, and environmental pollution are now causing a rise in extreme weather conditions, increased hurricane severity, shifting rainfall patterns, and sea levels. Such adjustments have a significant effect on ecosystem functioning, forest health, and human well-being (Boutabba, 2014; Dar & Asif, 2018; Shobande & Enemona, 2021).

Environmental threats are a source of concern for the general population and a factor in political, social, and economic decisions (Ayeche et al., 2016; Shobande, 2022). Cutbacks in global CO₂ emissions are a crucial policy goal of global attempts to mitigate the adverse impacts of





© 2023 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent. climate change (Tamazian & Rao, 2010). In spite of this effort global energy-related CO₂ emissions increased by 1.7 percent in 2018, reaching an all-time high of 33.1 GT, the highest amount since 2013 and 70 percent higher than the annual rise since 2010 (Shobande, 2021). This massive rise in CO₂ emissions runs counter to the Paris Climate Agreement's goal of reducing CO₂ emissions. According to the IEA (2018) study, global CO₂ emissions are rising as a result of strong global economic growth, slower energy conservation activities, and lower fossil-fuel prices.

In the same vein, carbon emissions in Africa, on the other hand, have been rising. Carbon emissions, for example, have risen from 302.94 million tonnes in 1970 to 1.22 billion tonnes in 2010 and then to about 1.37 billion tonnes in 2019 (Our World in Data, 2020). Africa is also the world's poorest continent, with 413 million people living in poverty in 2015. Africa is now feeling the effects of global warming, with more droughts, malnutrition, wars, disease transmission, migration, and floods (Serdeczny et al., 2017). As a result, it is critical to comprehend the underlying factors behind Africa's rising carbon emissions in order to devise strategies to mitigate the problem before it worsens.

However, in the context of global warming, ICT development may result in environmental concerns, particularly in terms of energy use and carbon emissions. According to Salahuddin and Alam (2015), ICT device-related power consumption is growing at a rate of 7% per year, resulting in increased carbon emissions (Chen et al., 2019; J. Wang et al., 2019). Others argue that the advancement of ICT will allow certain high-energy-consuming businesses to be replaced, therefore lowering carbon emissions (Lu, 2018). In the same vein, ICT has enhanced human connections and introduced numerous innovations that appear to stimulate economic growth, decrease income inequality, promote financial development, and promote inclusive education (Asongu et al., 2018). These accomplishments, while commendable, should not obscure the reality that ICT may also be used to support low-carbon development. Finally, there is no consensus on the impacts of ICT on the environment.

Theoretically, the interaction between ICT and the environment can be classified into three distinct levels (Awad, 2022; O. A. Shobande, 2022). The effects of ICT itself are considered firstorder or direct effects, for example, the energy consumption and waste generated in producing ICT products or services. The second-order effects focus on the sustainability impacts of greater ICT use and application (e.g., energy reductions achievable by intensive use of ICT in transportation). The possibility that rebound effects may revoke the gains caused by first-order effects, such as boosted power consumption caused by cheap energy costs obtained through increased energy efficiency. Thus, performance enhancements in ICT could indirectly result in higher carbon emissions if energy consumption is not decreased but increases due to efficiency improvements. However, there are three significant rebound effects in the existing literature: direct, indirect, and economy-wide. According to Awad (2022), a direct rebound effect implies that price reductions stemming from energy efficiency increase the demand for ICT goods, leading to higher energy consumption. An indirect rebound effect occurs when the efficiency of a resource causes its price to decrease, making other goods more desirable. In addition, economic rebound effects are associated with alterations in consumption habits (Charfeddine and Kahia, 2021). Because of ICT-induced monetary and energy price decreases, intermediate and final goods become cheaper, thereby changing consumption habits (Charfeddine and Kahia, 2021). However, a large part of the impetus behind digitalisation throughout society and the economy has been to reduce emissions and energy demand. Digitalisation and energy scenarios indicate that energy consumption must be reduced and shifted from other energy sources to electricity while launching a renewable electric power infrastructure (Awad, 2022). Since the production and use of digital devices have increased over the last decades, the direct effects of digitalisation - i.e., emissions caused by the production, use, and disposal of ICT products and services have also increased (Charfeddine and Kahia, 2021). For digitalisation to contribute to decarbonization, its favourable effects, such as reducing energy utilisation and accelerating the transition to renewable energy sources, must outweigh its harmful effects.

ICT facilitates market competition as well as foreign and domestic investment. Mighty ICT has triggered a rise in economic activities at all levels thereby increasing the level of FDI. The empirical studies performed by increasing numbers of researchers have revealed that FDI can enhance the ecological performances of host countries through technological spillover effects which are also called the "Pollution Halo Hypothesis" (Shobande & Enemona, 2021; Sokhanvar, 2019). FDI is also helpful to diminish the emission level of host economies and also promote the development of a low-carbon emission economy in host countries by using cleaner and renewable energy from renewable sources (Jahanger, Usman, & Balsalobre-lorente, 2022). The scholars argued that when the investment location is changed in terms of population feature, income level, and geographical ecological, then FDI influence on the environment is also significantly different (Hasanov et al., 2018). FDI campaigns have helped quicken economic growth in developing economics and its potential influence on the environment over the past decade is now being debated (Usman & Jahanger, 2021; Yang et al., 2020). Considering that foreign-invested enterprises in Africa mostly are highly polluting, it is of great practical significance to investigate the impact of foreign invested enterprises using ICT hardware and software on CO2 emissions.

Similarly, foreign direct investment (FDI) as a macroeconomic variable, is critical in promoting an economy's development and growth, particularly when domestic reserves are insufficient to meet local investment needs (Sokhanvar, 2019). However, it has the potential to degrade the environmental quality of the host country. The current empirical research on the impact of FDI on CO2 emissions is equivocal (Shahbaz et al. 2018). Furthermore, its three theoretical aspects are responsible for its inclusivity and diversity. First, the pollution-haven theory demonstrated that weak environmental laws in host nations may attract greater FDI from profit-driven companies seeking to avoid costly regulatory compliance in their home countries (Shao et al., 2019). As a result, FDI has a negative impact on the environment.

The pollution-halo theory states that the multinational company complies with international environmental standards and promotes green technology to neighboring nations (Ali et al., 2020), implying that FDI inflows reduce carbon emissions and enhance environmental quality (Naz et al., 2019). Lastly, the scale-effect hypothesis revealed that multinational companies significantly contribute to increase the industrial output of host countries, which ultimately leads to more energy consumption and enhance the overall pollution level (Ahmad et al., 2020). (Ahmad et al., 2020). Considering African countries, the current study is identifying which aspect is most dominant between FDI and environmental quality, and providing insightful implications.

Henceforth, ICT has a direct impact on FDI inflows through the route of increasing global connectivity, and thus may be regarded a determinant of FDI inflows. Improvements in ICT enable developing countries to embrace technology from industrialized countries outside of their borders, which is critical for economic progress. ICT can also have an indirect impact on FDI inflows by influencing the other drivers of the latter. Advanced ICT infrastructure, for example, increases a country's appeal to export-oriented FDI inflows. In other words, sophisticated ICT infrastructure offers logistical support for export while also increasing the country's appeal to international investors that is foreign direct investment. The increased use of ICT, particularly the broad usage of the internet, allows the society hosting nation to enhance the openness of many operations, reducing corruption and removing barriers to FDI influx (Mote et al., 2016).

Henceforward, according to recent ICT literature, Africa has a lot of space for ICT penetration when compared to more mature economies in Asia, Europe, and North America, where ICT penetration has hit saturation thresholds (Pénard et al., 2012; S. A. Asongu, 2013; Tchamyou 2016; S. A. Asongu & Nwachukwu, 2016; S. Asongu, 2015). Over the last decade, Africa's ICT technology has grown steadily. According to figures from the International Telephone Union, mobile cellular subscribers rose from 45.4 in 2010 to 65.5 in 2013, and then to 77.8 in 2017. Fixed broadband connections have risen from 0.2 in 2010 to 0.3 in 2012, and then to 0.4 in 2017. The number of people accessing the internet rose from 12.1 to 21.8 between 2013 and 2017

(Muazu et al., 2019). Policymakers should use this opportunity for ICT penetration to address pressing policy challenges in the era of sustainable change, such as global warming and environmental pollution. The present research extends the underlying strand of literature by assessing the importance of ICT in modulating the effect of FDI on the quality of environment dynamics. Such a positioning is also motivated by attendant gaps in FDI- and environmental quality centric contemporary studies.

Empirical studies on ICT and FDI impact on environmental quality have grown intensively (Asongu et al., 2018; Haseeb et al., 2019; Lu, 2018; Asongu et al., 2018). Additionally, the majority of these studies continue to generate mixed results. These mixed findings could partly be explained by differences in the econometric technique used, the time frame and the sample of countries in the study. In addition, existing studies have ignored the role and the significance of FDI through which ICT may affect environmental quality. This could, however, be helpful to identify key factors on which policy makers could operate to draw better environmental outcomes from the worldwide digital revolution. Thus, prior empirical studies on the effect of ICT development on environmental quality have primarily focused on developed countries' experiences, with very few concentrating on developing economies, particularly in Africa.

The study designs for most of the earlier studies have been group country studies, which failed to account for potential cross-sectional dependency (CSD) in their analysis, which might led to misleading results. A shock in one country may be transmitted to others due to globalization and increasing integration. In this case, cross-sectional correction is anticipated. Failure to acknowledge this possibility could produce misleading results (Shobande, 2021). Consequently, regardless of whether the previous studies reported a positive or negative impact of ICT on the environment, their conclusions were most likely misleading. That is to say, ignoring CSD in the analysis will produce inaccurate results and, hence, inappropriate policy recommendations and implications.

To fill this gap, the study investigate the moderating effects of ICT and FDI on the quality of environment in selected African countries. Specifically, our aim is to provide answers to the following questions: is ICT adoption harmful to the environment? If so, what is the indirect channel from ICT through FDI to environmental quality? What are then the policy implications for sustainable development? In addition, the present study used techniques that have been overlooked in prior studies and that are robust for cross-sectional dependence and heterogeneity. Hence, this research has offered more efficient and unbiased findings than earlier studies in contemporary literature. More specifically, since all the studies that have addressed this matter within Africa have ignored the above issue, these findings have provided policymakers with robust and accurate recommendations.

This study is relevant for a number of reasons. Firstly, although African countries accounts for less than 3% of the global carbon emissions, these emissions are expected to increase within the next decades in the region, given the ongoing economic and institutional reforms aimed at increasing economic growth, enhancing industrialization and economic diversification, improving transportation systems and responding to the energy crisis. Moreover, the modernization, automation and digitization of the production process needed to achieve these goals are expected to foster ICT adoption and diffusion, thus raising legitimate concerns about their impact on the environment. In the same vein, Africa is one of the less resilient regions to the adverse effects of climate change, and their vulnerability is exacerbated by their high dependence on revenues from the exploitation of natural resources. Similarly, African countries have responded to the global calls for action on climate change with laudable policy frameworks as well as other ancillary agreements and pacts with measures to attenuate the impact of climate change (Avom et al., 2020). Thus, understanding the determinants of the quality of environment provides an empirical basis for an effective fight against global warming. Unlike existing studies, the current study analysis is not only restricted on the direct effect of ICT penetration on environmental quality

but also the study highlight the moderating effect of ICT and FDI on environmental quality in Africa.

The remainder of the paper is laid out in the following manner. The literature review is presented in Section 1.2, and the methodology and data are presented in Section 2. Section 4 presents the empirical findings and debates, while Section 5 presents the conclusions and policy consequences.

1.1. Literature review

The effect of ICT and economic growth on CO2 emissions has gotten a lot of attention in the literature over the last two decades. Regarding the nexuses between ICT and CO2 emissions, the scholars are divided into different classes. The first aspect investigates the direct effect of ICT on carbon emissions. To begin with, it is thought that ICT contributes to the improvement of environmental quality by lowering greenhouse gas (GHG) emissions through increased energy efficiency (Ishida, 2015). Furthermore, Lu (2018) investigates the effect of ICT, economic growth, financial development, and energy use on CO₂ emissions in 12 Asian countries. CO₂ emissions are reduced with the use of ICT; however, economic growth, financial development, and energy demand allow CO_2 emissions to rise. Lee and Brahmasrene (2014) contend in another study that increasing Internet usage rate decreases CO_2 emissions at the national level.

In addition, the advancement of ICT would result in higher energy efficiency and lower CO_2 emissions. Ozcan and Apergis (2018) used panel data to investigate the impact of Internet use on CO_2 emissions in developing economies. The observational results show that Internet use in emerging economies reduces CO_2 emissions. Zhang and Liu (2015) also use the STRIPAT model to look at the contribution of the ICT industry to CO_2 emissions in different parts of China. The study's findings indicate that ICT will help reduce CO_2 emissions. S. A. Asongu, Le Roux, et al. (2018) used a generalised method of moment (GMM) model to investigate the effect of ICT on CO_2 emissions for 44 Sub-Saharan African countries. The findings indicate that ICT has a positive impact on CO_2 emissions; moreover, advanced ICT use (square of ICT) reduces CO_2 emissions and aids in improving environmental quality.

Another group of studies claims that the use of ICT is harmful to the environment because it emits a large quantity of CO_2 emissions. Salahuddin and Alam (2016) do the same thing, estimating the impact of economic growth and ICT on CO_2 emissions across OECD countries. According to the findings, any 1% growth in Internet use results in a 0.16 percent increase in CO_2 emissions. In addition, Lee and Brahmasrene (2014) look at the relationship between economic growth, Internet use, and CO_2 emissions for nine ASEAN countries from 1991 to 2009. The findings show that using the Internet has a positive effect on both CO_2 emissions and economic growth.

However, previous research has indicated that there is no significant connection between Internet usage and environmental quality (Asongu, Le Roux, et al., 2018). Baloch et al., (2018) recently looked at the relationship between ICTs, economic growth, financial development, and environmental quality in developing economies. From 1990 to 2015, the study's observational results were focused on panel mean group (MG) and augmented mean group (AMG) estimation methods. The empirical findings show that ICTs have a significant impact on CO_2 emissions, that the moderating influence of ICT and financial development stimulates CO_2 emissions, that economic growth leads to CO_2 emissions, and that the interaction between ICT and GDP reduces pollution levels.

Authors from another aspect use a non-linear framework to investigate the effect of increasing ICT penetration on the environment. According to the authors, the effect of ICT on the environment is described by an inverted U-shaped curve similar to the Environmental Kuznets Curve. Such a relationship suggests that environmental degradation initially increase with ICT adoption until a certain threshold. After this threshold, an increase in ICT adoption lessens environmental degradation, indicating that higher levels of ICT penetration are associated with reductions in

environmental degradation in the long-run. Using this framework, Añón Higón et al. (2017) investigated the effect of ICT on carbon emissions in a panel of 142 countries between 1995 and 2010. The empirical findings support the inverted U-shaped relationship between ICT and CO2 emissions for the global and sub panels of developed and developing countries. However, only developed countries have reached the threshold level of ICT while developing countries are at the increasing phase of the curve. In the same vein, Asongu et al. (2018) examine the effect of increasing ICT penetration (measured by mobile phone and internet penetration) on CO2 emissions in forty-four countries from SSA from 2000 to 2012. The results from a Generalized Method of Moments (GMM) estimator show that internet adoption have a net positive effect on per capita CO2 emissions, whereas an increase in mobile phone adoption has a net negative effect on CO2 emissions from liquid fuel consumption.

The last aspect investigates the relationship between ICT and environmental quality assuming that this relationship is moderated by macroeconomic variables. In this perspective, authors include an interactive term between ICT and macroeconomic variables in their econometric model. For instance, Asongu, et al. (2018) analyzes the moderating role of ICT on the relationship between trade openness and carbon emissions in 44 counties from SSA over the 2000–2012 period. The empirical results reveal that ICT diffusion, when complemented with trade openness could reduce CO2 emissions. Similarly, Danish et al. (2018) find that ICT and economic growth significant. They conclude that the advancement of ICT due to economic growth enhances environmental quality through decreasing CO2 emissions.

Another stream of studies looked at the relationship that exists between the environmental quality and the FDI. Although some research back up the pollution halo theory, others back up the pollution haven theory. The countries under study, the econometric approach used, data sources, conceptual and theoretical framework, and pollution and FDI proxies all contribute to the inconclusiveness (Letchumanan & Kodama, 2000).

A variety of empirical studies have looked into the effect of FDI on environmental quality. Zhang (2011) elaborated on the role of financial development to environmental degradation in China, stating that foreign direct investment (FDI) was primarily used in carbon-intensive production techniques, resulting in increased CO₂ emissions. Asghari (2013) used the fixed and random effect approach to test the validity of the pollution haven hypothesis in MENA countries. The findings showed that FDI inflows improved the environmental quality of MENA countries, confirming the pollution haven hypothesis. Wang et al. (2013) looked at both the positive and negative implications of FDI, concluding that FDI improved labour productivity, economic growth, and innovation in the host city, but it also resulted in pollution and unemployment. Seker et al. (2015) looked at the effect of FDI and GDP on CO₂ emissions in Turkey from 1974 to 2010. The findings revealed that FDI has a small but positive effect on CO₂ emissions, while GDP has a strong impact. Sun et al. (2017) used the ARDL model to validate the effect of trade openness and FDI inflows on CO₂ emissions, finding that both trade openness and FDI increased CO₂ emissions and supported the evidence of the pollution haven hypothesis.

Contrarily, for 20 nations, Solarin and Al-Mulali (2018) looked at the effect of FDI inflows on carbon footprints, ecological footprints, and CO₂ emissions. The common correlated effect (CCE) estimator and augmented mean group (AMG) estimation were used. FDI inflows and urbanisation were found to reduce emissions in developed countries while increasing pollution in developing countries. Liu et al. (2018) investigated the dynamics of work and spatial agglomeration effects in environmental pollution and FDI for the Chinese economy, concluding that FDI had a negative influence on various forms of environmental pollutants in China. Similarly, Zafar et al. (2019) used data from the United States from 1970 to 2015 to investigate the impact of FDI on the ecological footprint. The results indicated that FDI had a negative relationship with the ecological footprint, based on the ARDL model and the Zivot-Andrews unit root test.

1.2. Econometric model and data source

The study used data from six leading African countries ranked by the World Bank from 1970 to 2019, as well as the Cross-Sectional ARDL method of estimation is adopted to examine the relationship between the FDI, ICT and the quality of environment. The panel is made up of (n = 6) cross sections of (T = 49) time-series dimensions pooled together a total of 294 observations were obtained. As the dependent variable, CO₂ emissions (metric tonnes per capita) is used as a measure for environmental quality, while FDI is the foreign direct investment net inflow ratio of GDP. In the literature, several proxies have been used to measure ICT. Internet users (per 100 people) were used as a measure for measuring Internet usage in this analysis (Aón Abbasi & Riaz, 2016; Higón et al., 2017; Sadorsky, 2012). GDP per capita is an indicator of economic growth (constant 2010 USD). Real domestic credit to the private sector per capita is an indicator of financial development. The variables were chosen based on previous research. The World Bank's World Development Indicators provided the data for the above variables (WDI).

1.3. Interaction

Using the mechanism described by Jaccard and Turrisi (2003) the interaction of ICT and FDI on environmental quality is calculated. As a dependent variable, this entails estimating auxiliary regression of the product of two variables against the variables separately. The equation is written as follows:

 $(FDI_{it} * ICT_{it}) = \rho_0 + \rho_1 FDI_{it} + \rho_2 ICT_{it} + \mu_{it}$

Where the white noise error term is denoted by μ_{it} : $\mu_{it} \approx \text{ iid } (0, \sigma v^2)$. The interaction term is derived by generating the residual of the estimated regression.

1.4. Model construction

An econometric model based on related literature is developed to capture the relation between ICT, FDI, and the environmental quality, considering economic growth and financial development as control variables following the work of Danish, Khan, et al. (2018) and Ozcan & Apergis (2018). In this empirical study, the following model is estimated:

 $lnCO_2 = f(lnICT, lnFDI.lnGDP, lnFD)$

 $lnCO_{2it} = \rho_0 + \rho_1 lnICT_{it} + \rho_2 lnFDI_{it} + \rho_3 lnGDP_{it} + \rho_4 lnFD_{it} + \mu_{it}$

$$lnCO_{2it} = \rho_0 + \rho_1 lnICT_{it} + \rho_2 lnFDI_{it} + \rho_3 lnGDP_{it} + \rho_4 lnFD_{it} + ln(FDI_{it} * ICT_{it}) + \mu_{it}$$

Equation (14) explains the relationship between ICT, FDI, and environmental quality, while equation (15) explains the relationship as well as the interaction impact of ICT and FDI on environmental quality in six African countries. In the above mentioned equation, CO2 emissions are used to assess environmental quality, ICT refers to information and communication technology as measured by Internet penetration. In addition, FD stands for financial development, GDP for economic growth, and FDI for foreign direct investment inflow. Country and time are indicated by the letters i and t.

1.5. Cross-sectional dependency test

The Pesaran CD, Pesaran scaled LM, and Breusch-Pagan LM tests were used to look for dependencies or independencies in the residual terms. The CD test statistic proposed by Pesaran (2004) is computed as follows using the pairwise correlation coefficient bij among the cross-sectional residuals:

$$CD_P = \sqrt{rac{2T}{z^2 - z}} \sum_{i=1}^{z-1} \sum_{j=i+1}^{z} \hat{
ho}_{ij}
ightarrow (0, 1)$$

The Breusch and Pagan (1980) LM test can be used to test for cross-sectional dependency in heterogeneous panels in a fixed n case and as T. The test is computed using the formula:

$$\textit{LM}_{\textit{BP}} = \textit{T}\sum_{i=1}^{z-1}\sum_{j=i+1}^{z}\hat{\rho}_{ij}^2$$

The Breusch and Pagan 1980 LM test is distributed asymptotically beneath the null as a × 2 with $\frac{z^2-z}{2}$ degrees of freedom. Conversely, the test is not appropriate when $z \to \infty$. As such, Pesaran (2004) suggested a scaled version form of the LM_{BP} test is stated as:

$$\textit{CD}_{\textit{LM}} = \sqrt{\frac{1}{\textit{Z}^2 - \textit{Z}}} \sum_{i=1}^{\textit{z}-1} \sum_{j=i+1}^{\textit{z}} (\textit{T} \hat{\rho}_{ij}^2 - 1)$$

According to Pesaran (2004), the CD_{LM} is distributed asymptotically as N (0, 1) under the null, with $T \rightarrow \infty$ first, and then, $z \rightarrow \infty$.

1.6. Homogeneity test

Henceforth, following the cross-sectional dependency tests, the Pesaran and Yamaga (2008) test was used to determine if the slope parameters were heterogeneous or homogeneous. The delta tilde $(\hat{\Delta})$ and delta tilde modified $(\hat{\Delta}_{adj})$ test statistics make up the PesaranYamagata test. These two tests are calculated as follows:

$$\hat{\Delta} = \sqrt{Z} \left(\frac{Z^{-1} \hat{\mathbf{s}} - l}{\sqrt{2l}} \right)$$

$$\hat{\Delta}_{\textit{adj}} = \sqrt{Z} \Biggl(\frac{Z^{-1} \textbf{s} - \textbf{H}(\hat{v}_{\textit{i}} \textbf{T})}{\sqrt{\textit{var}(\hat{v}_{\textit{i}} \textbf{T})}} \Biggr)$$

Where $H(\hat{v}_i T)$, $var(\hat{v}_i T) = \frac{2l(T-l-1)}{T+1}$. The above test statistics are predicted under the null hypothesis of slope homogeneity as against the alternative hypothesis of slope heterogeneity.

1.7. Panel unit root tests

Since the series in our study include macroeconomic variables such as ICT, income per capita (GDP), EPC, and carbon dioxide emissions, we start by checking the series' stationarity. As a consequence, it's possible that the sequence is nonstationary, and the results aren't economically or statistically reliable (M. A. Baloch et al., 2018). Meanwhile, there are two types of unit root tests for panel data: first generation and second generation panel unit root tests. If there are dependencies between countries, first generation unit root tests, also known as traditional unit root tests, produce inaccurate results. As a result, newly developed second generation unit root tests, such as Pesaran (2007)'s CIPS and CADF panel unit root test, are commonly used in recent literature. Because of their resistance to cross-sectional dependencies, these tests were considered. The CADF statistic is calculated using the following formula:

$$\Delta Y_{it} = \mathbf{e}_i + \mathbf{c}_i Y_{i,t-1} + \mathbf{b}_i \overline{Y}_{i,t-1} + \sum_{j=0}^{\rho} \mathbf{a}_{ij} \Delta \overline{Y}_{t-j} + \sum_{j=1}^{\rho} \varphi_{ij} \Delta Y_{it-j} + \pi_{it}$$

Where Y_{t-j} and ΔY_{t-j} indicate the cross-sectional means of lagged levels and first differences of distinct series respectively. Based on the CADF test, the CIPS test is computed as:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i$$

Where $CADF_i$ is the t-statistic under the CADF test.

1.8. Panel cointegration tests

The Westerlund and Edgerton (20072007) test was then used to investigate the cointegration properties of the variables. The group statistics (Ga and Gt) that test for the existence of cointegration in at least one cross-sectional unit and the panel statistics (Pa and Pt) that test for the existence of cointegration in all cross-sectional units make up the Westerlund-Edgerton's test. The following expressions are used to compute the group statistics for this test:

$$\mathsf{G}_t = \frac{1}{\mathsf{Z}}\sum_{i=1}^{\mathsf{Z}}\frac{\varphi_i}{\mathsf{SE}\hat{\varphi}_i}$$

$$G_{\alpha} = \frac{1}{Z} \sum_{i=1}^{z} \frac{T \varphi_i}{\varphi i'(1)}$$

Where G_t and G_{α} are statistics for group averages. The group statistics null and alternative hypotheses are as follows:

 $H_0: \sigma_i = 0$ cointegration is present for all i

$H_1: \sigma_i = 0$ cointegration is not present for at least some i

Once H_0 is rejected, at least one cross-sectional unit must be integrated. Failure to reject H0, on the other hand, implies that all groups have cointegration. The following expressions are used to calculate the panel statistics of this test:

$$P_T = rac{\hat{arphi}_i}{\mathsf{SE}\hat{arphi}_i}$$

 $P_{\alpha} = T\hat{\varphi}_i$

 P_{α} and P_{T} denote panel statistics. The panel statistics null and alternative hypothesis are as follows:

 $H_0: \sigma_i = 0$ cointegration is present for all i

$H_1: \sigma_i = \sigma < 0$ cointegration is not present for at least some i

 H_1 denotes that the adjustment phase to the long-run equilibrium is homogeneous across all groups. As a result, failure to reject H_0 implies the presence of cointegration across the entire panel.

Cross-sectionally augmented ARDL estimator

The long-run and short-run relationship between carbon emissions, economic globalization, financial development, agriculture valueadded, and natural resources is established by applying crosssection augment ARDL (CS-ARDL). The CS-ARDL is robust not only for nonstationarity and endogeneity but also overcome heterogeneous slope and cross-section dependence problems and provides efficient results (Chudik et al., 2017; Chudik and Pesaran, 2015). The equation for CS-ARDL is provided as:

$$\Delta CO_{2it} = \gamma_i + \sum_{i=1}^{\sigma} \gamma_i \Delta CO_{2it-1} + \sum_{i=1}^{\sigma} \gamma_{it} \tau_{it-1} + \sum_{i=1}^{\sigma} \gamma_{it} \vartheta_{it-1} + \pi_{it}$$

The averages for cross-sections are denoted by $\vartheta_t = (\Delta CO_{2it}, \gamma_{it})$, where γ_{it} is for all explanatory variables such as ICT, FDI, economic growth and financial development.

1.8.1. Empirical results

Table 1 summarises the descriptive statistics of the variables used in the analysis over a given number of years:

Table 1 shows the descriptive statistics for the above factors for a survey of 6 major African countries from 1970 to 2012. All variables are converted into natural logarithms, as mentioned previously in the data source. Statistics in Table 1 descriptively reveals that, for the sample of African countries, environmental quality ($InCO_{2it}$) on average is 10.817 which is fairly large with standard deviation of 1.287 compared to $InGDP_{it}$ (M = 6.937, SD = 1.601), $InFD_{it}$ (M = 3.419, SD = 0.986) and $InICT_{it}$ (M = 1.225, SD = 1.167). In comparison to all the other factors, $InFDI_{it}$ had the maximum mean value of 18.966 with a standard deviation of 2.715, followed by total labour. The standard values for skewness and kurtosis should be zero and three, respectively, for an observed sequence to be normally distributed or symmetric. The skewness and kurtosis values in Table 1 indicate that none of the observed series fits a normal distribution. We affirm that the series is not normally distributed after confirming that none of the kurtosis and skewness values for the above variables satisfy the conditions of normality. This is consistent with the Jarque-Bera normality test, which shows that the null hypothesis that all observed series obey a normal distribution is rejected. The results of the homogeneity test are shown in Table 2 going forward.

Table 1. Summary statistics of variables (in natural logarithm)							
	InCO _{2it}	InICT _{it} InFDI _{it}		InGDP _{it}	InFD _{it}		
Mean	10.81721	1.225358	18.96606	6.937237	3.419664		
Median	10.94896	1.110923	1.110923 19.56333 6.970571		3.342384		
Std. Dev.	1.287340	1.167676	1.167676 2.715122 0.909296		0.986194		
Skewness	-0.244199	0.349689	-1.431635	0.003657	-0.249296		
Kurtosis	2.293266	1.972336	6.567246	2.122314	1.873214		
Jarque-Bera	7.933573	16.61115	224.9283	8.281658	16.32109		
Probability	0.018934	0.000247	0.000000	0.015910	0.000286		
Sum	2790.839	316.1423	4893.243	1789.807	882.2733		
Sum Sq. Dev.	425.9117	896.4706	1894.575	212.4924	249.9528		
Observations	258	258	258	258	258		

All the variables are transformed into logarithm forms. The data for 22 African countries were considered over the period 1970 to 2019. The Jarque-Bera test is used to determine whether a given series follow a normal distribution or not. It tests the null hypothesis that, a given series is normally distributed.

Table 2. Results from the Pesaran-Yamagata's homogeneity test						
Test	Statistics	P-value				
$ ilde{\Delta}_{test}$	8.320*	0.000				
$ ilde{\Delta}_{Adjtest}$	8.969*	0.000				

Note: ***indicates statistical significance at % level.

We confidently reject the null hypothesis of the slope coefficients being homogeneous at a degree of significance of 1 percent using the measured values of the delta tilde $\tilde{\Delta}_{test}$ and modified delta tilde $\tilde{\Delta}_{Adjtest}$ and their respective P-values. As a result, variability exists across all of the studied variables within the different nation classes, necessitating the use of heterogeneous panel approaches in which parameters vary across particular cross-sections inside the panels. Table 3, on the other hand, focuses on the results of the CD test in addition to the homogeneity test.

The probability values for the different CD test values of all variables can be tested by pointing to the CD test values and their corresponding probability values, resulting in the rejection of the null hypothesis of cross-sectional independence. As a result, it can be concluded that there is ample cross-sectional dependence among variables across all countries and panels. When formulating domestic policies to account for external likely effects, it is critical to understand this variability and cross-sectional correlation.

The value of using a second generation panel unit root test that accounts for cross-sectional dependence where there is strong evidence of heterogeneity and cross-sectional dependence among groups of African economies for a variety of variables. According to Phillips and Sul (2003), the efficiency of estimation outcomes may be reduced significantly where cross-sectional similarities and variability occur among countries inside a panel data set, and this is generally ignored in estimation. As a result, the Pesaran's CIPS and CADF are used as some of the second generation panel unit root checks in the analysis. Because of the observed heterogeneity and cross-sectional dependency, the panel data approaches used in this analysis take into account problems of heterogeneity and cross-sectional dependence in order to have valid and consistent performance.

Table 4 shows the results of the panel unit root analyses, which are based on Pesaran's CADF and CIPS and are stable in the presence of heterogeneity and cross-sectional dependency.

In order to exploit possible hidden features, this study considers estimation with constant plus trend. The null hypothesis of non-stationarity of the variables at levels is rejected for InFDI it but not for the other variables, according to both tests. This provides clear proof that at levels InFDI it does not have a unit root, while the other variables do, and they do not have a unit root in their first difference. After confirming that certain variables are stationary simultaneously at level while others are at their first difference, we used a panel cointegration test to see whether there is

Table 3. Results from cross-section independence test							
	InCO _{2it}	InICT _{it}	InFDI _{it}	InGDP _{it}	InFD _{it}		
Pesaran CD-test	20.081	24.487	11.630	21.615	6.232		
P-value	0.000	0.000	0.000	0.000	0.000		
Pesaran Scale LM-test	74.283	106.793	25.208	83.375	48.186		
P-value	0.000	0.000	0.000	0.000	0.000		

Note: *** indicates the statistical significance at 1% level.

Table 4. Results from CADF and CIPS panel unit root test							
At level			At first difference				
Series	Series CADF CIPS			CIPS Verdict			
InCO _{2it}	-2.627	-2.797	-4.880*	-5.561*	Integrated (1)		
InICT _{it}	-2.778	-2.355	-3.854*	-4.060*	Integrated (1)		
InFDI _{it}	-3.137*	-3.806*	-5.316*	-6.420*	Integrated (0)		
InGDP _{it}	-2.919	-2.810	-4.488*	-5.338*	Integrated (1)		
InFD _{it}	-2.432	-2.544	-3.714*	-6.176*	Integrated (1)		

Note: D represents the first differences, ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

a long-term association between the variables. The results of the Westerlund and Edgerton (2007) bootstrap panel cointegration test are summarised in Table 5 respectively.

The result using environmental quality $(InCO_{2it})$ as the response variable shows that all of the variables are cointegrated based on their stable likelihood value for the panel of the countries, as the hypothesis of no cointegration is rejected at a 1% level of significance for the statistics Gt and Pt. The findings based on stable p-values provide a better proof of cointegration between the variables studied. As a result, we should deduce that the variables under consideration have a long-term relationship.

Subsequently having established that the series are cointegrated, it is of interest to pin down to estimate the short run as well as the long-term relationship using the CS-ARDL panel regression model estimator. Table 6, as a result, outlines the summary of the key findings from the CS-ARDL panel regression model estimation approach. A further detailed analysis follows.

All the series with the exclusion of financial development ($lnFD_{it}$) were recognized to have positive and significant effect on the amount of CO₂ emissions (quality of environment). All things being equal a 1% upsurge in Information and Communication Technology ($lnICT_{it}$) significantly increase the amount of CO₂ emissions ($lnCO_{2it}$) by 0.37%, suggesting that ICT contributes in deteriorating the quality of environment in these 6 leading African countries. This may be explained by the fact that developing African countries are yet to reach their wealth tipping point; as wages rise, people buy more goods and services, which is harmful to the climate. With increasing wages, for example, the tendency to use ICT raises the construction and manufacture of ICT appliances and machines, as well as service and electronic waste, both of which increase energy consumption and CO2 emissions. Furthermore, the negative impact of ICT on environmental quality may be attributed to inefficient energy usage by a significant number of ICT equipment in leading African countries. Policy initiatives can be implemented to advance the ICT sector, resulting in increased energy usage and lower CO2 emissions. The outcome is in line with the results of Wan Lee and Brahmasrene (2014) for Asian countries, Salahuddin et al. (2016) for OECD

Table 5. Results from bootstrap panel cointegration test							
Dependent variable InCO2it		Constant		Constant + trend			
Test type	Statistic	Value	Value p-value		<i>p</i> -value		
Westerlund	Gt	-3.484	0.004	-3.576	0.027		
	Ga	-3.246	0.999	-2.727	1.000		
	Pt	-8.687	0.001	-8.817	0.009		
	Pa	-3.912	0.959	-3.107	0.999		

Table 6. Cross-sectional ARDL estimate results							
	Dependent Variable InCO _{2it}						
		Model One		Model Two			
Variables	Coefficient	Std. Err	t. Statistics	Coefficient	Std. Err	t. Statistics	
Long-run Results							
InICT _{it}	0.407	0.051	7.91	0.072*	0.026	2.75	
InFDI _{it}	0.214	0.025	8.40	-0.049	0.029	-1.70	
InGDP _{it}	0.643	0.042	14.99	-0.141*	0.051	-2.75	
InFD _{it}	0.418	0.065	6.39	0.319*	0.036	8.83	
In(ICT * FDI) _{it}				0.632	0.054	11.744	
Short-run Results							
ECM(-1)	-0.549	0.147	-3.72	-0.342	0.108	-3.16	
$\Delta lnICT_{it}$	-0.185	0.072	-2.55	0.060	0.020	2.91	
$\Delta lnFDI_{it}$	0.464*	0.155	2.99	-0.114	0.273	-0.41	
$\Delta lnGDP_{it}$	0.144	0.042	3.41	-0.142	0.052	-2.72	
$\Delta lnFD_{it}$	-0.348	0.456	-0.76	0.248	0.869	0.28	
$\Delta ln(ICT * FDI)_{it}$				-0.014	0.002	-4.76	
Number of Groups	6			6			
R-squared	0.63			0.66			
Adjusted R-Square	0.49			0.51			
F(93, 175)	2.49	0.00		2,63	0.00		
CD Statistic	2.72	0.00		3.61	0.00		

Notes: * as well as ** signifies the null hypothesis rejection at 1% as well as 5% level of significance.

countries, Aón Higón et al. (2017) for global outlook, Danish et al. (2018) for developing markets, and Danish et al. (2019) for low-income countries.

In terms of the effect of FDI on environmental quality, the results show that FDI has a positive and significant impact on CO2 emissions. As a result, a 1% increase in $lnFDI_{it}$ corresponds to a 29% increase in $lnCO_{2it}$ respectively. The findings show that FDI increases human ecological demands, and that foreign plants built in these six leading African countries may not use optimal processing methods, requiring more labour and using a lot of electricity, resulting in increased environmental degradation. The outcome backs up PHH's claim and is consistent with (M. A. Baloch et al., 2019) results for BRI countries.

Economic growth also has a positive effect on CO2 emissions. This is because a 1% rise in InGDP it results in a 33% increase in InCO 2it. The result supports the results of Dong et al. (2018) for China, which show that increased economic growth degrades environmental quality by rising CO2 emissions. Leading African countries have a great chance of boosting big economic sectors like agriculture, industry, and transportation. Another explanation may be that economic growth increases economic activity by increasing spending, purchasing, and consumption, which contributes to increased CO2 emissions and, as a result, deterioration in environmental standards. Furthermore, studies show that increased energy intake results in increased CO2 emissions. It's possible that this is because developing African countries depend on conventional energy sources including gas, oil, and coal. Another explanation is that the energy systems used in these countries are obsolete, affecting environmental quality.

The first model's final result suggests that financial development has a positive and statistically significant effect on CO2 emissions. This arises from the fact that a 1% increase in InFD it corresponds to an 18% increase in InCO 2it. This may be explained by the fact that financial development increases human demand, and the financial sector allocates capital to businesses, which boosts production operations, resulting in increased industrial waste and environmental degradation. Financial development further encourages infrastructure construction by offering medium- to long-term equity loans.

This infrastructure programmes, which entail the construction of bridges, train lines, and seaports, necessitate vast amounts of soil, water, and air resources, causing environmental degradation. Another explanation may be that financial development boosts the purchasing power of the general population by providing low-interest loans. This allows consumers to purchase expensive items such as apartments, automobiles, and air conditioning, both of which put enormous strain on the climate. As a result, the group of these six leading African countries should take the environmental effects of financial development seriously. The results are in line with Charfeddine (2017) and (Mrabet & Alsamara, 2017) for Qatar.

According to Brambor et al. (2006), if the impact of ICT on environmental quality is dependent on the inflow of FDI into the selected countries, then focus should be paid to the interaction term $ln(ICT * FDI)_{it}$ rather than the individual terms $lnICT_{it}$ or $lnFDI_{it}$. The positive sign on $ln(ICT * FDI)_{it}$ indicates that FDI inflows speed up the positive influence of ICT on CO2 emissions. Overall, this study finds that ICT is a critical FDI factor since a well-developed ICT infrastructure decreases perceived geographical gap, which attracts foreign investors. ICT not only lowers the cost of communication and improves the process of exchanging information among foreign affiliates, but it also provides advanced opportunities for foreign affiliates (Veljanoska, Axhiu & Husejni, 2013). This suggests that rising FDI inflows triggers an increase in energy demand due to the widespread use of ICT equipment, which worsens environmental quality by increasing CO2 emissions. One potential regulation would be that as FDI inflows grew, so did spending in the ICT sector in these leading African economies, and as a result, ICT use increased as a percentage of total energy demand. Due to the manufacture and use of ICT equipment, energy needs have increased, further degrading environmental efficiency.

Henceforth, Table 6 presents the outcomes of the short-run CS-ARDL test. The empirical outcomes reveal that while considering model 1 that is the model without interaction, ICT and FD have negative relationship with the amount of CO2 emissions but connection is insignificant with the FD, meaning that increase the level of ICT tends to decrease the amount of CO2 emissions thereby enhancing the quality of environment. The amount of GDP and FDI in the short-run have positive relationship with the amount of CO2 emissions, meaning that increase in economic growth and FDI lead to an increase in the amount of CO2 emissions in the short run and hence deteriorate the quality of environment. Lastly in view of model 2 that is the model with interaction term, the results reveal that in the short run the interacting term of ICT and FDI have negative relationship with the amount of CO2 emissions and hence improve the quality of environment in the short run. The speed of adjustment represented by ECM for model one is-0.54 and model two -0.342, showing that the adjustment toward equilibrium is 54% for model one and 34% for model two.

The statistics of the Pesaran CD and its corresponding P-value that test for the cross-sectional dependence indicate that the outcome reject the null hypothesis which confirm the presence of cross-sectional dependence across the concern countries of study (P-value<0.005) for mode 1 and model 2. The R2 value shows the fitness of a regression model, and its value for the model 1 is 0.63 and model 2 is 0.66, which shows a very good fit of the regression model, and approximately 63 and 66 percent of the differences in the dependent variable in both of the models are explained by

the explanatory variables used in the models. At the same time, the F-statistics that is concern with measuring the significance of all the regressors jointly in the models has a coefficient value of 2.49 for model 1 and 2.63 for model 2 are significant statistically at a 1 percent level of significance, and this signifies the fact that the variables are jointly significant.

2. Conclusion and policy recommendation

Researchers have looked into the role of ICT in CO2 emissions in the past. Previous research have been criticized for using econometric panel models to disregard cross-country dependencies and heterogeneity, resulting in unreliable results. The interaction of ICT and FDI on CO2 emissions has been overlooked in regional studies. This empirical study examines the role of information and communication technology (ICT) in the relationship between FDI and environmental quality for six leading African economies from 1970 to 2022. The study used CS-ARDL model for short run and long-run estimation, which takes into account for cross-sectional dependency and heterogeneity in a data set.

The study's empirical findings point to a few intriguing conclusions: First, information and communication technologies (ICT), foreign direct investment (FDI), economic growth, and financial development degrade environmental quality. Second, the moderating influence of ICT and FDI (ICT*FDI) allows CO2 emissions to rise. The study's observational results suggest important policy implications that should be taken into consideration.

Finally, this research not only adds to the prevailing knowledge, but it also has significant policy ramifications and offers some insights for prospective researchers. To counter balance and reduce CO2 emissions, policymakers must concentrate on tax strategies, new market models, and ICT equipment services and operations. Smart use of ICT-enabled technology would minimise CO2 emissions by bringing revolutionary improvements to mobile users such as online financial transactions, online purchasing, browsing, and booking.

Thus, the study recommends continuous investment in ICT infrastructure and education regarding the importance of implementing environmentally sustainable practices. Similarly, energy conservation is critical because the Internet appears to indirectly increase energy usage by increasing the overall productivity of the economy, which may subsequently degrade the environment. Finally, ICT is a potential enduring solution to enable e-sustainability and to increase awareness of the potential danger of poor environmental management. Policymakers should adopt strategies to promote smarter cities, electrical grids, transportation systems, industrial processes, and energy-saving advances in order to reduce global carbon dioxide emissions. Furthermore, the government should use a smart tax mechanism to prevent environmental damage.

As a result, the introduction of new ICT devices, non-ICT industries fostering clean environmental sectors, alternative business models, and tax policy ramifications would conserve energy while also reducing CO2 emissions and e-waste. These countries' governments should develop strategies to curb unsustainable ICT usage and launch green ICT programmes. Such ICT penetration policies should be designed to promote the implementation, access, communications, efficiency, and scope of ICT in order to sustainably reduce CO2 per capita emissions. This legislative agenda will help to move forward on certain stalled environmental goals, such as Agenda 21 and Multilateral Environmental Agreements (MEAs). In other African nations, national schemes like Rwanda's Information Technology Authority (RITA) should be promoted. RITA brings together and coordinates the nation's information technology resources (Chemutai, 2009).

According to this study, developing countries would lose out on opportunities if they delay greater access to and utilisation of information systems and technology. As a result, policymakers must better realise that the degree of ICT is critical for attracting potential investments and influencing environmental sustainability in order to effectively restructure their markets, draw international investors, and eventually gain and maintain comparative advantage. The study

concludes that developing countries should be given more support for green ICT growth if they are to break out of their current "equilibrium pit" in the immediate future.

Future research might explore the influence of governance on the ICT and environmental quality within the context of country-specific and panel mandates. Furthermore, while this study is confined to African countries, it is interesting to expand the investigation to other areas and continents.

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