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MACROECONOMIC DETERMINANTS OF CO_2 EMISSIONS: EVIDENCE FROM SELECTED TOP AFRICAN COUNTRIES

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Abstract: This research inspired by the growing threats to environmental quality examines the mitigating effects of Information and Communication Technology (ICT) on carbon emissions of African leading economies. ICT behaviour is essential for economic growth, but its environmental consequences cannot be underrated. As such the study contributes to the prevailing literature by examining the effect of ICT, economic growth, foreign direct investment, and financial development on the quality of the environment from 1970 to 2019, in the study we considered 10 leading African countries. To achieve the given objective, the study applied the Pooled Mean Group (PMG) panel method of estimation to determine the long-run as well as the short-run dynamic relationship. The results of the study show that economic growth, financial development, and ICT have a positive and significant effect on carbon emissions while foreign direct investment has a negative relationship with the amount of carbon emissions. The study recommended that energy-efficient technologies should be applied not only at the manufacturing level but also at transport and household levels. The implementation of environmentally sustainable the technology would help improve the quality of the environment, increase sustainability in the long term and conserve resources for future generations.

Keywords: ICT, GDP, financial development, FDI, PMG-ARDL.

Introduction

Sustainable development, mitigation of global warming and climate change also caused researchers and policymakers to focus on the CO_2 emission determinants. This helps the implementation of environmental protection initiatives and policies needed to reduce emissions. A leading example of a recent global effort is the Paris Agreement of December 2015, where 196 nations adopted a historic global strategy to tackle climate change in the coming years. The agreement laid down firm commitments to curb global warming to below 2^{o}C (Zhang & Liu, 2015). This helps the implementation of environmental conservation initiatives and policies needed to reduce emissions.

Recently, almost all economic activities, like foreign direct investment, marketing, and trade, are reliant on up-to-date sources of ICT. In the same vein, ICT increases access to the obtainability of information, utilising natural form of resources and inspiring economic growth (Latif *et al*., 2018). The improvement of ICT has transformed the industrial sector in the last few decades by structural reform, and the period of economic growth is thus growing as well as stimulating human development (Danish, Zhang, Wang, & Latif, 2019). ICT's share in global GDP is growing dramatically across different regions, but despite all the positive role it has played in economic growth, ICT puts tremendous pressure on environment and the natural resources all over the world (Lee & Brahmasrene, 2014). However, considering the contribution of ICT to different fields, ICT, like the internet, mobile telephone, or satellite, will play a key role in solving the major challenges of climate change as well as sustainable development.

The ICT effect on the quality of the environment is either to be positive or negative, as a result of the fact that ICT constitute two sound effects on CO_2 emissions, the first of the effect is the use effect while the second effect is the substitution effect. Firstly, the use effect entails the provisions of ICT machinery, equipment, the energy consumption rebound effect, extracting rare earth materials as well as e-waste contributes to CO_2 emissions (Añón, Gholami, & Shirazi, 2017). More specifically, the method of installation and operation of new ICT devices is known to be extremely energy intensive (Ozcan & Apergis, 2018a). Both the processing and manufacturing of ICT devices are also responsible for growing CO_2 emissions (Asongu, Le Roux, & Biekpe, 2018).

Secondly, the substitution effect entails physical goods substitution with computer generated equipment like emails in place of writing letters as well as e-books replacing printed reading books (Shabani & Shahnazi, 2019), smart transport, such as smart transport networks, road traffic cameras, GPS, as well as travel services, tend to reduce the outside activities, for instance, e-commerce, online shopping, e-business and teleconferencing minimise the requisite for business travel. The use and production of ICT also increase energy efficiency, resulting to a decrease in CO_2 emissions (Danish, Khan, Baloch, Saud, & Fatima, 2018a). Henceforth, according to recent ICT literature, there is considerable potential for ICT infiltration in Africa as compared to more developed economies in Asia, Europe and North America where ICT penetration has reached saturation levels (Asongu, 2018). Policymakers should exploit this opportunity for ICT penetration to address major policy problems like CO_2 emissions and global warming in the era of sustainable development.

Similarly, in the transition from the MDGs (Millennium Development Goals) to the SDGs (Sustainable Development Goals), several positions are consistent with the view that extreme poverty has decreased in all regions of the world, except of Africa, where nearly half of the countries in the region have been left behind from achieving the MDG threshold for extreme poverty (World Bank, 2015). Indication of this extreme poverty phenomenon is in stark contrast to the fact that the sub-region experienced more than two decades of revival of economic growth that started in the mid-1990s (Asongu, Le, & Biekpe, 2017). Therefore, it is reasonable to conclude that in order to counter total deprivation, the fruits of economic growth are not sufficiently trickling down to unprivileged fractions of the population. In addition, it is also reasonable to combine the resulting economic growth with greenhouse gas emissions, which were reported to constitute a major challenge to environmental sustainability in the post-2015 development period (Opeyemi, Philip, Evans, & Adeyemi, 2016)

The economic growth of Africa is projected to slightly upsurge from 3.2% in 2018 to 3.4% in 2019 as well as 3.7% in 2020 (United Nations, 2019). This sum of an economy's expected growth is based on many variables that include prospective resource availability. The development of the economy can cause adverse environmental problems due to the over-exploitation of natural resources, which can contribute to the dilapidation of wildlife habitats and climate change (Lu, 2017). In view of these facts, we can notice that Africa has recently experienced a revival of growth over two decades, after decades lost in the search for economic development (Fosu, 2015). It is reasonable to argue that the underlying burgeoning economic growth was related to environmental degradation and pollution as well as greenhouse gas emissions.

In recent years, partly as a result of large rises in Foreign Direct Investment (FDI) inflows, many African countries have seen their economic growth improve (Aliyu & Ismail, 2015). One cause of concern is that the continent's growing openness to the global economy, which encouraged its access to more international investment, is likely to result in higher energy consumption and significant pollution-emission implications. There has been an assertion that foreign investment policies are primarily resource in most African countries – mainly dependent on extractive industries and are frequently correlated with negative environmental consequences (Azapagic, 2004). Under this substance, people on the continent will be less responsive to emissions, and as such would be hesitant to either promote the formulation or strengthening of environmental regulations. This issue is of great significance, particularly given African countries that are very poor compared to developed nations in terms of environmental regulations.

Moreover, the financial system of Africa when compared with the rest of the world is the least developed system of finance. For example, (Acheampong, 2019) argue that prior to the global financial crisis, financial intermediation and domestic credit provision in Africa was worse than in other developing regions. For example, the average ratio of domestic credit to private sector as a percentage of GDP in sub-Saharan Africa was 17%, while the average ratio of domestic credit to private sector in other developing regions ranged from 32% to 43%. In 2007, total liquid liabilities as a percentage of GDP for sub-Saharan Africa were below 30%, while for other developing regions the minimum was not below 40% (Allen, Carletti, Cull, Qian, & Senbet, 2011). The financial system in Africa has recently been strengthened but still has the least developed financial system relative to other developing regions (Acheampong, 2019). However recognising the effect of financial development on Africa's carbon emissions would have consequences for sustainable development and climate change policies. Therefore, if financial development is found to minimise carbon emissions, then sustainable development goals in Africa will become easier to attain. On the other hand, if financial development in Africa is found to increase carbon emissions, then this may impact emission modelling models and climate change policies.

Henceforth, it is very important to examine the effect of ICT, economic growth, foreign direct investment and financial development on African carbon emissions, despite the fact that Africa is the lesser contributor to global carbon emission, still the amount of carbon emissions has been increasing in the region. For example, from 884.53 million tons in 2000 to 1.19 billion tons in 2010 and from 1.23 billion tons in 2012 to 1.29 billion tons in 2015 and around 1.33 billion tons in 2017 (WDI, 2019). Additionally, as of 2015, Africa is the poorest region in the world with a total of 413 million people living below the poverty line. Africa is already experiencing the negative impact of global warming in the form of rising drought, poverty, wars, disease spread, migration and floods (Serdeczny *et al*., 2017). In order to devise strategies to reduce it before it gets worse, it is therefore important to consider the fundamental forces behind the growing carbon emissions in Africa.

The nexus between ICT, economic growth, financial development, foreign direct investment and CO_2 emissions has been explored in several studies. With regard to the ties between ICT and CO_2 emissions, two schools of thought have been formed. One group of researchers has concluded that by reducing CO_2 emissions, ICT increases environmental quality (Moyer & Hughes, 2012; Al-Mulali *et al*., 2015a; Salahuddin & Gow, 2016; Ozcan & Apergis, 2017a). Another group of scholars argued that the development of ICT increases the consumption of energy and thus the amount of CO_2 emissions (Sadorsky, 2012; Lee & Brahmasrene, 2016; Belkhir & Elmeligi, 2018). The influence of ICT on CO_2 emissions throughout different regions of the world remains under study. Therefore, to fill this void the current study examines the nexus between ICT, economic growth, financial development, foreign direct investment and CO_2 emissions over the period of 1970 to 2019 while considering ten leading African countries according to the IMF 2019 ranking.

This paper contributes to literature in many ways, despite the impetus for the research. First, the research examines the simultaneous impact of ICT, economic growth, foreign direct investment, and financial development on environmental quality by considering Africa while most of the preceding studies consider developed regions or countries. Secondly, the study will formulate a financial development index using PCA (Principal Components Analysis), taking into account three banking sector measures (broad money supply, domestic credit by the banking sector and domestic credit by the private sector) as well as three stock market measures (stock market capitalisation, stock market value exchanged and stock market turnover), contrary to the prevailing literature that use a single or a mixture of limited and different proxies for the financial development measurement (Shahbaz *et al*., 2013a; Al-mulali *et al*., 2015; Khan *et al*., 2017a; Hafeez *et al*., 2019b).

As a result of the numerous indicators used in the previous literature to measure financial development, there is no agreement on the exact relation between environmental quality and financial development. The study will seal this research void through the use of a comprehensive and single index of financial development. Third, the study introduces ICT as one of the deciding factors of environmental quality, as most previous studies only consider macroeconomic variables without considering the position of ICT, as it will help policymakers implement sustainable development policy and ICT investment. Fourthly, as most of the previous research regarding the quality of the environment have applied a panel form of data model that failed to account for the issue of cross-sectional dependency and heterogeneity that would be among the essential reason for the inconclusive outcomes. The current study used advanced form of econometric techniques that accommodate heterogeneity and cross-sectional dependency so as to get accurate and unbiased findings.

The rest of the paper is structured according to the following. Section 2 provides a summary of the literature, accompanied by a study of the methods and data in Section 3. Section 4 presents analytical results and debates, accompanied by findings and policy consequences in Section 5.

Literature Review

Climate change is a big problem facing the world because of environmental issues. The primary cause of climate change is CO_2 emissions. Several CO_2 emission determinants are debated in the literature. The effect of ICT as well as economic growth on CO_2 emissions has gained tremendous attention in literature for most of the last two decades. With regard to the ties between ICT and CO_2 emissions, the researchers are divided into two categories. First, ICT is thought to contribute positively to improving environmental quality by reducing emissions of Greenhouse Gases (GHGs) through energy efficiency achievement. Furthermore, as far as the connection between ICT and CO_2 emissions is concerned, Lennerfors, Fors, and Rooijen (2015) address ICT as a means of environmental protection towards social change. Añón, Gholami, and Shirazi (2017) claim in another study that ICT first worsens the equality of the environment and, with time, it improves by reducing CO_2 emissions.

Through the use of a sample of ASEAN countries and a co-integration panel methodology, Lee and Brahmasrene (2014) both show a positive effect of ICT on CO_2 emissions in ASEAN countries from 1991 to 2009. As for the environmental impact, the use of ICTs helps minimises the level of emissions (Ollo-lópez & Aramendía-muneta, 2012). Al-Mulali, Sheau-Ting, and Ozturk (2015) found in a study the heterogeneous impact of internet retailing on CO_2 emissions for developed and developing nations. Internet use lowers CO_2 emissions in developed countries but internet retailing has an insignificant effect on developing countries' CO_2 emissions. The explanation for the heterogeneous effect may be attributed to the slow development of the Internet in developing countries. Coroama, Hilty, and Birtel (2012) found that the ICT decreases Greenhouse Gas (GHG) emissions by means of efficient production and consumption of energy patterns. Asongu *et al*. (2017) also looks at the effect of ICT on CO_2 emissions in 44 sub-Saharan African countries using a Generalised Moment Method (GMM) model. With regard to the regional disparities in China, Zhang and Liu (2015) find the effect of the ICT industry on CO_2 emissions using the provincial data model STRIPAT.

The report suggests that in China, the ICT industry is lowering the CO_2 emission rates. Ozcan and Apergis (2018) examined the effect of Internet use on CO_2 emissions in developing countries. The study concludes that increased Internet use is reducing CO_2 emissions in 20 emerging economies. Most recently, Lu (2018) looks at the effect on CO_2 emissions in 12 Asian countries of ICT, economic growth, financial development and energy use. Using ICT lowers CO_2 emissions; however, economic growth, financial progress and energy use cause CO_2 emissions to increase.

The second category of studies claims that by increasing a significant amount of CO_2 emissions, the use of ICT harms the environment. In a similar vein, Salahuddin and Alam (2016) examine the influence of ICT and economic growth on CO_2 emissions on the countries of OECD. The empirical results of the study reveal that a 1% increase in the use of the internet escalates CO_2 emissions by 0.6%. In a similar vein, Lee and Brahmasrene (2014) investigate the relationship between internet uses, economic growth and CO_2 emissions for nine emerging Association of Southeast Asian Nations (ASEAN) countries over the period of 1991 up to 2009 respectively.

The findings have shown that the use of the internet has a significant positive effect on both CO_2 emissions as well as economic growth. Some previous literature, however, indicated an insignificant relationship between environmental quality and Internet usage (Asongu *et al*., 2017). Recently, Danish, Khan, Baloch, Saud, and Fatima (2018) examined the effect of ICT on CO_2 emissions in developing countries as well as introduce a novel approach of estimation for the impact of interaction between economic growth and ICT on CO_2 emissions. The results from the study reveals that mobile use and internet use increase the amount of CO_2 emissions and hence deteriorate the quality of the environment, on the other hand, the increasing use of mobile phones and the internet with increasing income mitigates the level of CO_2 emissions and improve the quality of the environment.

The majority of the research on the nexus between carbon emissions and economic growth is embedded in the hypothesis of Environmental Kuznets Curve (EKC). The hypothesis of EKC suggests that economic growth and carbon emissions have an inverted form of U-shaped relationship. Thus, carbon emissions rise at the early stages of economic growth, but carbon emissions decrease beyond a certain degree of economic growth (Grossman & Krueger, 1995; Al-Mulali, Tang, & Ozturk, 2015; Ahmad *et al.*, 2017; Charfeddine & Mrabet, 2017). The findings of empirical research on the effect of economic growth on carbon emissions remain extremely controversial. For example, Ahmad *et al*. (2017) used ARDL to analyse the nexus between carbon emissions and economic growth in Croatia, and the results show that the long-term inverted U-shape relationship between economic growth and carbon emissions confirms the EKC hypothesis.

Apergis and Ozturk (2015) used the GMM to inspect the link between carbon emissions and economic growth in the case of Asian countries. The results suggest that the EKC hypothesis is confirm. Similarly, in order to examine the relationship between carbon emissions and economic growth for 43 developing economies, Narayan and Narayan (2010) utilised panel techniques of cointegration. Their results support the hypothesis of EKC in Middle East as well as South Asian countries while the hypothesis of EKC was not supported in the case of Latin America, East Asia and Africa.

Economic growth is reasoned to be the key determinant behind the tenacious upsurge in global carbon dioxide emissions. The link between carbon emissions and economic growth has been studied widely. Some studies are of the opinion that economic growth has an adversative consequence on the quality of the environment by escalating the amount of carbon dioxide emissions as supported by Omri, Daly, Rault and Chaibi (2015) for MENA countries, Begum, Sohag, Abdullah, and Jaafar (2015) for Malaysia, Ahmad *et al*. (2017) for Croatia, Charfeddine and Mrabet (2017) for MENA countries and Dong, Sun, and Dong (2018) for China and Al-mulali, Saboori, and Ozturk (2015) for Vietnam given empirical evidence to suggest that an increase in economic growth is capable of rising energy consumption, which eventually exacerbates CO_2 emissions. Whereas other studies reveal that economic growth is essential to minimise the degradation of the environment, for example, a study by Yeh and Liao (2017) for Taiwan, Boufateh (2019) for the USA, Ma and Jiang (2019) for China, Aye and Edoja (2017) for 31 developed countries and Acheampong, (2018) for 116 countries worldwide showed a decline in CO_2 emissions with a rise in the economic growth and hence improve the quality of environment.

There is no doubt that the relevance of FDI to economic growth, especially in emerging countries such as African countries with unfulfilled investment needs, is paramount. It is important, however, to take into account the literature that addresses the environmental implications of FDI. Theoretically, depending on which dimension or channel is dominant, FDI may have positive as well as negative impacts on the environment. There are three forms of dimensions regarding this relationship that is pollution haven hypothesis, the pollution halo hypothesis as well as scale effect hypothesis (Shahbaz, Ali, & Roubaud, 2018). At the same time, there may be a conflicting effect of FDI on the quality of the environment, and perhaps the empirical evidence shows mixed empirical outcomes for such a reason. For example, Ren, Yuan, Ma, and Chen (2014) stated that FDI adds to CO_2 emissions, while studying the FDI impact of CO_2 emissions in China. They also dismiss the claim put forth in Turkey review by Ozturk and Oz (2016), which indicates that FDI is spreading greener technologies to the host country and contributing to environmental progress in developing countries. However, later findings by Zhang and Zhou (2016), using Chinese regional data, Liu, Hao, and Gao (2017) and Jiang, Zhou, Bai, and Zhou, (2018) report negative effects of FDI on CO_2 emissions using Chinese city-level data. This means we have mixed facts, even in a single country like China. Evidence from other emerging economies by Paramati, Ummalla, and Apergis (2016) reports that while FDI facilitates higher economic development, it also contributes to greater environmental degradation.

Tang and Tan (2015) state that the key determinants of growing CO_2 emissions in the case of Vietnam are income as well as FDI. Abdouli and Hammami (2018) specify that FDI adds to a substantial upsurge in the consumption of energy as well as CO_2 emissions in the case of MENA economies, whereas other country-level heterogeneities exist in the relationship. Correspondingly, a study by Zhu, Duan, Guo, and Yu (2016) on the countries of ASEAN-5 using the regression of Panel Quantile states that, with the exception of the 5th quantile, the FDI effect on carbon emissions is negative and becomes significant at higher quantiles. Conversely, in the instance of the countries of ASEAN-5, Baek (2016) applies the dynamic panel's PMG (Pooled Mean Group) form of estimator and the outcome shows that FDI appears to upsurge CO_2 emissions. Zakarya, Mostefa, Abbes, and Seghir (2015) also explores the relationship regarding Inflow of FDI and carbon dioxide emissions, using evidence from BRICS countries. They show that there is a significant and positive effect of economic Inflow of FDI on CO_2 emissions.

In theory, there are two major opposing views on the effect of financial development on the quality of the environment. One of the schools of thought is the argument that the development of financial sector enhances the quality of the environment via research and development (Frankel & Romer, 1999). An economies that are developed financially are thus attracting foreign direct investment and further boosting R&D activities that would ultimately improve the quality of the environment (Acheampong, 2019). In addition, (Zagorchev, Vasconcellos, & Bae, 2011) claimed that financial development encourages technical advances that, through economic growth, minimise environmental degradation. Furthermore, Tamazian and Rao (2010) believe that a financial sector that is well developed can make government and firms to invest in projects that are protect the environment by getting access to a lower cost capital. Some researchers have found that financial development increases the efficiency in energy consumption and productivity of the industry and thus helps to minimise energy consumption and carbon dioxide emissions (Gow, & Ozturk, 2015; Al-Mulali, Tang, *et al*., 2015; Dogan & Seker, 2016; Ghorashi & Rad, 2018; Salahuddin, Saud, Chen, Haseeb, Khan, & Imran, 2019).

In contrast, the second school of thought suggests that the nature of the environment could be deteriorated by financial development. According to Shahbaz (2013), financial development may accelerate industrialisation, which could lead to industrial pollution and environmental degradation. Via the household, business as well as wealth impact channels, financial development may also reduce the quality of the environment. Through the households channel effect, financial development would make consumers or household to get access with money or a credit that is cheap to patronize big-ticket form of items like irons, refrigerator, washing machines, houses, automobiles and air conditioners that require a huge amount of energy and hence increase the consumption of energy (Kahouli, 2017; Shahbaz, Hoang, Mahalik, & Roubaud, 2017), that in turn deteriorate the quality of environment.

In similar vein, concerning the business effect channel, development of financial sector allows firms to get access with a lower cost capital that will enable them to enlarge their business capacity through the hiring of additional labours, purchasing more equipment and machines as well purchase or build a new plant that will escalates the intensity of energy use and carbon dioxide emissions as well (Dar & Asif, 2017). Regarding the channel of wealth effect, (Acheampong, 2019) argues that financial development will increase the diversification of risk in the economy, which is crucial for an economy to generate income. Therefore, financial development would enhance business as well as consumer confidence and hence upsurges economic growth that would in turn increase the consumption of energy and carbon emissions as well.

Several studies provide strong evidence that the financial sector is evolving, causing increased carbon dioxide emissions (Charfeddine & Khediri, 2015; Javid & Sharif, 2016; Dar & Asif, 2017; Xing, Jiang, & Ma, 2017; Ali *et al.,* 2018; Cetin, Ecevit, & Yucel, 2018; Paramati, Alam, & Apergis, 2018). The studies have found reasons for the financial sector's positive impact on CO_2 emissions. Firstly, stock market growth will help the listed companies boost their funding networks, decrease financing costs, reduce operating risk, make new investments and thereby increase energy use and CO_2 emissions. Second, financial development will increase environmental degradation through increased rates of foreign direct investment inflows. Eventually, a country's developed financial system will make it much easier for consumers to buy durable consumer products which can lead to higher carbon emission levels (Raza & Shah, 2018).

Given the presence of inconsistency in the literature together with the knowledge gaps, the current study contributes to the prevailing literature by constructing an index of financial development through the use of five different indicators of financial sector as well the study intend to look at the role of ICT on the quality of environment considering the panel of top 10 leading African countries over the period of 1970 to 2019 using heterogeneous panel method of analysis.

Econometric Model and Data Source

Data Description

For this analysis, we employ annual panel data over the period 1970–2019 for top 10 leading African countries. The list applies to the top 10 leading African countries including Nigeria, South Africa, Egypt, Algeria, Morocco, Kenya, Ghana and Tanzania. The choice of time span selection is based on availability of the data. The

CO_2 emission (metric tons per capita) is used as a proxy for environmental quality. Economic growth is measured in per capita GDP (Constant USD 2010). Different studies have used many measures to quantify ICT; however, ICT is measured by smartphone usage (per 100 people), in this analysis. Foreign direct investment, which reflects the inflow of investment capital, was measured as a net inflow percentage of GDP. The weighted index of financial development is constructed by applying PCA to financial sector domestic credit (percentage of GDP), private-sector domestic credit (percentage of GDP), and private-sector domestic credit provided by banks for the 10 leading African countries. The data were obtained from World Bank Development indicators for all variables used.

Model Specification

Following the work of (Amri, 2018; Asongu, 2018; Danish *et al*., 2018a; Lu, 2018) with some modification, the study adopts the following linear model to empirically investigate the effect of ICT, economic growth, FDI and financial development on the quality of environment, as such the model is specified as follows:

$$InCO_{2it} = \beta_{it} + \beta_1 ICT_{it} + \beta_2 GDP_{it} + \beta_3 FDI_{it} + \beta_4 FD_{it} + \mu_{it} \quad (1)$$

where i = 1, 2, …, N as well t = 1, 2, …, T symbolises the country and time period, means the CO_2 emissions per capita, ICT_{it} is mobile users per 100 people, GDP_{it} represents real GDP, FDI_{it} represents the inflow of FDI, and FD_{it} stands for financial development index and μ_{it} symbolises an error term. All the variables are algorithmic in their normal form. Empirically, the predicted sign of β_1 is either positive or negative, due to the uncertain function of ICT in CO_2 emission. In addition, the predicted sign of GDP is positive since economic growth speeds up emission rates (Al-Mulali, Ozturk, & Lean, 2015), and so we predicted the regression coefficient β_2 to be positive.

In the same vein, FDI could be expected to either be positively or negatively related with carbon emissions based on the Pollution heaven hypothesis and pollution halo hypothesis, as such could either be positive or negative. The impact of financial development on CO_2 emissions is regarded as unexpected. Henceforth, financial development leads to the deterioration of the environment, the claim put forth by Ozcan and Apergis (2018). Financial development is thus helpful in reducing CO_2 emission levels Salahuddin *et al*. (2015). So, the sign of is unexpected, either it is negative or positive.

Cross-sectional Dependence Tests

Cross-sectional dependence is important in the panel data analysis, particularly if the panel consists of countries in a similar category such as developed, emerging and transition countries. A shock impacting one economy could also affect other economies due to globalisation, financial integration and foreign trade as well (Ozcan & Ozturk, 2019). The quest for cross-sectional dependency is therefore our first step and an important step in choosing the right econometrics tests to be used in the study. Based on Equation (2), we constructed the LM test statistic:

$$Y_{it} = \delta_{it} + \rho_i X_{it} + \beta_2 GDP_{it} + \mu_{it}$$
$$i = 1, \ldots \ldots \ldots, N \text{ and } t = 1, \ldots \ldots \ldots, T \quad (2)$$

where Y_{it} is a explained variable, X_{it} is a k×1 vector the explanatory variables, as well the subscripts i and t signify cross-section and the dimensions of time, correspondingly; δ_{it} and ρ_{it} represents the intercepts of the country-specific and the coefficients of the slope. In this setting, the null hypothesis of no cross-sectional dependency - for all t and i ≠ j – is tested contrary to the alternate hypothesis of the presence of cross-sectional dependency - for at least one pair of i ≠ j. Moreover, the test statistic of LM can be figured as in Equation (3).

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\beta}_{ij} \rightarrow d\, \chi^2_{N(N-1)/2} \quad (3)$$

where signifies an estimate of the sample for the residuals pair-wise correlation. Conversely, the LM statistics is not suitable with large N, in this circumstance, Pesaran (2007) recommended the ensuing) test statistics of Lagrange multiplier that is the scaled form of the LM test statistic:

$$CD_{lm} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\beta}_{ij}^{2}-1\right) \quad (4)$$

Beneath the null hypothesis of no cross-sectional dependency with first T→ ∞ as well N→ ∞ in any instruction (Ozcan & Ozturk, 2019). In the instance of large N relation to T, the test has significant size alterations. Consequently, Pesaran (2007) proposed to apply the ensuing CD test that is proper when N is greater than T.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\beta}_{ij} \quad (5)$$

The test of CD has a usual asymptotically normal distribution beneath the null hypothesis of no cross-sectional dependency with T → ∞ as well then N → ∞ in any direction (Nazlioglu, Lebe, & Kayhan, 2011). Nevertheless, the test of *CD* has the ensuing shortcoming: Where the average population pair-wise correlations happened to be zero, even though the essential individual population pair-wise correlations are not zero, test of *CD* will miss power. For that reason, Pesaran, Ullah, and Yamagata (2008) recommended a bias-adjusted form of the LM test, LM_{adj}, which uses the precise mean as well as variance of the LM statistic in event of large panels wherever first $T \rightarrow \infty$ as well $N \rightarrow \infty$. The bias-adjusted LM test statistic is demarcated as:

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\theta_{ij}^{2}-\vartheta_{Tij}}{\gamma^{2}T_{ij}} \rightarrow_{d} N(0,1) \quad (6)$$

where k denotes to the number of regressors, ϑ_{Tij} and y^2_{Tij} specify the exact mean as well as variance of $(T-k)\theta^2_{ij}$, correspondingly.

Slope Homogeneity Tests

While country-wide dependency is likely to be high, each country follows different methods in its development stages by developing different policies, making it crucial to test for country-wide slope heterogeneity (Wolde-Rufael, 2014). As a result, next among the steps is to examine the presence of heterogeneity in the slope coefficients in Equation (7) as well as (8). For this reason, we applied the Delta tests ($\tilde{\Delta}, \tilde{\Delta}_{adj}$), which were suggested by Pesaran, Ullah, and Yamagata (2008). There are four types of Delta tests ($\tilde{\Delta}, \tilde{\Delta}_{adj}, \hat{\Delta}$, and $\hat{\Delta}_{adj}$), but Pesaran, Ullah, and Yamagata (2008) state that $\tilde{\Delta}$, and $\tilde{\Delta}_{adj}$, tests have better size properties compared to $\hat{\Delta}$, and $\hat{\Delta}_{adj}$ tests. Therefore, we applied $\tilde{\Delta}$, and $\tilde{\Delta}_{adj}$ tests, which are defined in equation (7) and (8).

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{\sqrt{2k}}\right) \quad (7)$$

where k, $\bar{S}$ and N specify the number of regressors that are exogeneous, test statistic of (Swamy, 1970), as well as the dimension of cross-section, correspondingly. The properties of small sample of the $\tilde{\Delta}$ test could be enhanced underneath the error that is normally distributed on the basis of the following mean as well as variance bias-adjusted version of $\tilde{\Delta}$:

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-E(\bar{Z}_{i}T)}{\sqrt{Var(\bar{z}iT)}}\right)$$

where and $= k$ and $Var(\bar{z}iT) = \frac{2K(T-K-1)}{T+1}$ (8)

Panel Unit Root Test

Considering the observation of heterogeneity and cross-sectional dependence, the panel data methods adopted in this analysis consider heterogeneity problems and cross-sectional dependence in order to provide reliable and accurate results. Hence, Pesaran's (2007) CADF and CIPS unit root tests are applied. The test of Cross-sectional Augmented Dickey-Fuller (CADF) nurtures raises the cross-sectional unit root of ADF regressions by using the subsequent Equation (9):

$$\Delta y_{it} = \alpha_{i} + \rho_{i}y_{it-1} + \beta_{i}\bar{y}_{t-1} + \sum_{j=0}^{k}\gamma_{ij}\,\Delta\bar{y}_{it-1} + \sum_{j=0}^{k}\delta_{ij}y_{it-1} + \varepsilon_{it} \quad (9)$$

where α_i = deterministic term, k = lag order, and y_t = crosssectional mean of time t.

In the Cross-sectional Augmented IPS (CIPS) study, (1) t-statistics are removed from the measurement of individual ADF statistics (based on Eq. (9), (2) it permits cross-sectional dependence amongst observed countries, (3) it delivers reliable results even for small sample sizes, and (4) its perilous values are related with computed CIPS statistics.

$$CIPS = \frac{1}{N}\sum_{I=1}^{N} t_i\ (N,T) \tag{10}$$

where "$t_i(N,T)$" exhibits the statistics of the crosssectional augmented Dicky–Fuller.

Panel Cointegration Test

We use Westerlund's (2007) cointegration approach to investigate the nature of long-term relationships within variables. The test is conducted by evaluating the importance of the term error correction in a restricted model of panel error correction and is based on structural dynamics as opposed to the residual dynamics and as such is not influenced by common factor limitations. When the hypothesis of no error correction is rejected the null hypothesis of no cointegration is rejected. Westerlund's (2007) error-correction method reads as follows:

$$\Delta Y_{it} = \delta_i' d_t + \alpha_i Y_{it-1} + \lambda_i' X_{it-1} + \sum_{j=1}^{\rho i} \alpha_{ij}\, \Delta y_{it-j} + \sum_{j=0}^{\rho i} \gamma_{ij} \Delta X_{it-j} + \mu_{it} \tag{11}$$

α_i is the parameter for error correction, which defines the speed at which the system returns to equilibrium after an unpredicted shock occurs. $d_t = (1, t)'$ includes the deterministic elements, which include the constant and the trend with the corresponding parameter vector being $\delta_i = (\delta_{1i}, \delta_{2i})'$. In order to test the presence of cointegration, four tests of cointegration test were developed on the basis of least squares estimate of α_i in equation (11) as well as its t-ratio. Two of them are known as the statistic of the group mean while the other two are called the panel statistics.

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)}\ and\ G_\alpha = \frac{1}{N}\sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i\ (1)}$$

where, $SE(\hat{\alpha}_i)$ signifies the predictable standard error of $\hat{\alpha}_i$.$\hat{\alpha}_i(1)$. is the semiparametric kernel estimator of $\alpha_i(1)$. The alternative hypothesis of these tests is that the whole panel is cointegrated. Two other tests, which are proposed in the paper, are as follows:

$$P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})}\ and\ P_\alpha = T\hat{\alpha}$$

The null hypothesis suggests that the variables are not cointegrated, and the alternative hypothesis implies that there is cointegration among the variables.

The Pooled Mean Group (PMG) Estimator

This study employs an econometric method of estimation developed by Pesaran *et al*. (1999) known as PMG estimator. The econometric techniques can be divided into two different categories when dealing with panel data. First, it is possible to accommodate individual heterogeneity by estimating individual equations for each cross section and by combining the estimates of parameters. This is accomplished by the estimator of the Mean Group (MG) proposed by Pesaran *et al*. (1995), which can be seen to be a reliable though not inherently effective estimator of the heterogeneous average parameters. Instead, a dynamic fixed effects or other similar model may be used to pool the cross-sections. This method allows for different intercepts but includes slope parameters for all cross-sections to be similar, which can be a highly limiting assumption.

The PMG estimator, by capitalising on the merits of both methods, tries to find a compromise between these two opposing strategies. Short run coefficients are permitted to differ across countries (similar to the MG estimator) whereas long run coefficients are needed to be homogenous for all cross sections (similar to the estimator for fixed effects). The PMG estimator has many advantages over other methodologies. For example, the PMG estimator can be used irrespective of whether the variables are I(0) or I(1), and long- and short-run causality inferences can be made even if there is no formal detection of the cointegration. In addition, if there are variables in logarithms, the long-run coefficients can be interpreted as elasticity. Find the following equation for ARDLs (1,1,1,1,1,1):

$$Y_{it} = \rho_i Y_{i,t-1} + \sum_{j=0}^{i} \tau_{ij}{}' X_{i,t-j} + \pi_i + \epsilon_{it}$$

where ρ_i is an n × k vector of the logarithms of the explanatory variables, τ_{ij} is a k × 1 coefficient vector and π_i account for country specific effects. Equation (10) can be rearranged into an error correction model of the following form:

$$\Delta Y_{it} = \emptyset_{1,i}\left(Y_{i,t-1} - \varphi_{1,i}^{\prime X_{i,t-1}}\right) + \tau_{1,i}^{*\prime} \Delta X_{it} + \pi_i + \epsilon_{it}$$

where $\emptyset_{1,i} = -(1-\rho_i)$ and $\varphi_{ij} = \frac{\sum_j^1 \tau_{ij}}{1-\rho_i}$

In a similar manner, the remaining equations can be expressed as follows:

$$\Delta k_{it} = \emptyset_{2,i}\left(k_{i,t-1} - \varphi_{2,i}^{\prime X_{i,t-1}}\right) + \tau_{2,i}^{*\prime} \Delta X_{it} + \pi_i + \epsilon_{it}$$

$$\Delta h_{it} = \emptyset_{3,i}\left(h_{i,t-1} - \varphi_{3,i}^{\prime X_{i,t-1}}\right) + \tau_{3,i}^{*\prime} \Delta X_{it} + \pi_i + \epsilon_{it}$$

$$\Delta Y_{it} = \emptyset_{1,i}\left(Y_{i,t-1} - \varphi_{1,i}^{\prime X_{i,t-1}}\right) + \tau_{1,i}^{*\prime} \Delta X_{it} + \pi_i + \epsilon_{it}$$

$$\Delta nfe_{it} = \emptyset_{5,i}\left(nfe_{i,t-1} - \varphi_{5,i}^{\prime X_{i,t-1}}\right) + \tau_{5,i}^{*\prime} \Delta X_{it} + \pi_i + \epsilon_{it}$$

where, in each case, the remaining explanatory variable ΔX_{it} is a vector of n × k. Short-run coefficients are denoted by the τ * s. The importance of these coefficients suggests short-run causality from the associated explanatory variable to the variable depending upon. The ∅s represents the long run long run coefficients, the meaning of these coefficients will suggest that the associated variable has a long-run relationship to the dependent variable, and if the associated error correction term is both negative and significant, then it is also a source of long-run causality. The $\emptyset_s$ symbolizes error correction terms (ECTs). The inverse of the absolute value of these coefficients provides a speed of adjustment estimate.

Results and Discussions

The empirical findings of the analysis are summarized and discussed in this section.

Descriptive Summary

The descriptive statistics of variables used in the analysis regarding the number of years selected are listed as follows in Table 1.

The findings described in Table 1 presents the descriptive statistics for the above variables regarding the sample of top 10 leading African countries from 1970 to 2019. As already stated in the description of the data, all variables are translated into natural logarithms. Statistics in Table 1 descriptively discloses that, for the sample of leading African countries, FDI on average is 8.279 which is fairly large with standard deviation of 1.087 compared to carbon emissions (M = 4.305, SD = 0.704), financial development (M = 1.270, SD = 1.553) and ICT (M = 1.017, SD = 2.089). Economic growth on the other hand compared to all the other variables had the highest mean value of 10.497 with a standard deviation of 0.557.

In general, the usual value for skewness and kurtosis should be 'zero' and 'three' respectively, for an observed sequence to be normally distributed or symmetric. Table 1 findings per skewness and kurtosis give the impression that none of the series observed follows a normal distribution. Specifically, skew values indicate that the variables (economic growth, FDI and financial development) are negatively skewed, indicating that these variables flatter to the left relative to a normal distribution, whereas carbon emissions and ICT are positively skewed and favorable to the right. This also means that, for the first three distributions, the bulk of the results per sample are distributed to the negative side. Therefore, the distribution of GDP and financial development per kurtosis results are roughly mesokurtic (kurtosis values roughly 3) whereas FDI is leptokurtic (kurtosis values greater than 3).

Henceforth, carbon emissions and CIT among all variables had their kurtosis value to be lower than the usual value indicating that the curtosis curve is platykurtic for this distribution. After verifying that none of the kurtosis and skewness values for the aforementioned variables

Table 1: Descriptive statistics results

	$lnco_{2it}$	$lngdp_{it}$	$lnfdi_{it}$	$lnfd_{it}$	$lnms_{it}$
Mean	4.305	10.497	8.279	1.270	1.017
Maximum	5.701	11.754	10.063	2.915	4.902
Minimum	3.020	9.205	4.000	-3.892	-2.206
Std. Dev.	0.704	0.557	1.087	1.553	2.089
Skewness	0.226	-0.002	-0.720	-0.267	0.284
Kurtosis	1.874	2.216	3.245	2.367	1.674
Jarque-Bera	30.684 (0.000)	12.795 (0.001)	44.484 (0.000)	14.287 (0.000)	43.355 (0.000)
Observations	500	500	500	500	500

Note: All the series are translated into logarithm kinds. The data for 10 leading countries of Africa were considered over the period 1970 to 2019. The Jarque-Bera test is done to evaluate whether or not a particular series follows a normal distribution.

satisfy the normality conditions, we conclude that the series is not normally distributed. This is in line with the Jarque-Bera test for normality which provides strong evidence to reject the null hypothesis that a normal distribution follows all the observed sequence.

Correlation Matrix

Table 2 shows the correlation analysis between the five variables used in the study. It is evident from this analysis that carbon emissions has a statistically significant correlation with Africa's GDP, FDI, financial development, and CIT. A statistically significant and positive correlation is also observed between GDP and each of the variables, FDI, Financial development, and CIT. FDI is further identified to have a positive and significant link with financial development and CIT whilst financial development on the other hand is positively and significantly linked with CIT. Henceforth, CIT as the final variable is found to also have a positive and statistically significant correlation with all the other variables.

Homogeneity and Cross-sectional Independence Tests

Cross-sectional dependence and homogeneity among variables are critical in selecting additional econometric tests used in the analysis, such as unit roots and cointegration test. The analysis thus checked for cross-sectional independence among the series with Pesaran CD test of Pesaran (2004) and Pesaran-Yamagata

Table 2: Pearson correlation analysis

Variables		$lnco_{2it}$	$lngdp_{it}$	$lnfdi_{it}$	$lnfd_{it}$	$lnms_{it}$
$lnco_{2it}$	Pearson corr. Sig.(2-tailed)	1	0.727*** (0.000)	0.529*** (0.000)	0.715*** (0.000)	0.626*** (0.000)
$lngdp_{it}$	Pearson corr. Sig.(2-tailed)		1	0.579*** (0.000)	0.575*** (0.000)	0.702*** (0.000)
$lnfdi_{it}$	Pearson corr. Sig.(2-tailed)			1	0.333*** (0.000)	0.663*** (0.000)
$lnfd_{it}$	Pearson corr. Sig.(2-tailed)				1	0.6741*** (0.000)
$lnms_{it}$	Pearson corr. Sig.(2-tailed)					1

Note: ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

(2008) checked homogeneity with adjusted delta tilde test.

The results based on the homogeneity test are therefore illustrated in Table 3. Using the measured values of delta tilde ($\tilde{\Delta}_{test}$) as well as the adjusted delta tilde ($\tilde{\Delta}_{Adj\ test}$) and their respective P-values, we reject with certainty the null hypothesis that the slope coefficients are homogeneous at a significance level of 1%. This therefore means that heterogeneity occurs for all the variables evaluated in the various country groups, therefore it is important to follow heterogeneous panel methods in which parameters vary within the panels across individual cross-sections.

Table 4 shows the results from the CD test. It can be seen that the probability values of all variables for the different CD tests are significant at 1% level leading to the rejection of the null hypothesis of no cross-sectional dependency. Therefore, this gives the implication that in different panels there is sufficient cross-sectional dependence between variables across all countries. From a policy perspective, when formulating domestic policies to account for external potential impacts, it is important to consider this heterogeneity and cross-sectional correlation.

Panel Unit Root Tests

The CIPS and CADF of the Pesaran are implemented in the analysis as some of the second-generation panel test of unit root. Considering the existence of heterogeneity and cross-sectional dependence, the panel data methods adopted in this analysis consider heterogeneity problems and cross-sectional dependence in order to provide reliable and accurate results.

The results of the panel unit root tests, based on CADF and CIPS from the Pesaran, which are robust in the presence of heterogeneity and cross-sectional dependence, are described in Table 5. This study considers constant plus trend estimation so as to exploit possible hidden features. Both tests, depicts that the null hypothesis of non-stationarity of the variables at levels for carbon emissions, GDP, financial development, and ICT cannot be rejected but rejected when the variables are in their first difference whilst for FDI the null hypothesis of the absence of stationary was rejected at 1% level of significance. This gives strong evidence that, at levels carbon emissions, GDP, financial development, and ICT have unit root whilst in their first difference they have no unit root while FDI were found to have no

Table 3: Homogeneity test results

Type of Test	Test	Statistics	P-value
Pesaran-Yamagata (2008)		24.21 ***	0.000
		25.80***	0.000

Note: ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

Table 4: Cross-sectional dependency test results

Type of Test	$\mathbf{lnco_{2it}}$	$\mathbf{lngdp_{it}}$	$\mathbf{lnfdi_{it}}$	$\mathbf{lnfd_{it}}$	$\mathbf{lnms_{it}}$
Pesaran's CD Test	38.13 (0.00)***	26.72 (0.00)***	30.39 (0.00)***	24.68 (0.00)***	45.67 (0.00)***
Bias corrected scale LM test	154.58 (0.00)***	108.61 (0.00)***	95.44 (0.00)***	110.16 (0.00)***	214.14 (0.00)***
Pesaran Scale LM test	154.68 (0.00)***	108.71 (0.00)***	95.54 (0.00)***	110.26 (0.00)***	214.25 (0.00)***
Breusch-Pagan LM test	1512.50 (0.00)***	1076.38 (0.00)***	951.40 (0.00)***	1091.08 (0.00)***	2087.55 (0.00)***

Note: ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

unit root at level. Having confirmed that some variables have unit at their respective levels but stationary at their first difference while other happened to be stationary at level by not having a unit root at level, we went further to employ a panel cointegration test in order to examine the existence of long-term relationship among the variables.

Panel Cointegration Test

After confirming the stationary properties of the variables, the study then investigated the long-run structural relationship with Westerlund-Edgerton (2007) bootstrap cointegration test in relation to carbon emissions, GDP, FDI, financial development and ICT, due to the possible heterogeneity and cross-sectional dependence in the panel data. Furthermore, Table 6 presents the summary of the results.

The outcome with carbon emissions $lnco_{2it}$ as the response variable reveals that, all the variables per their robust probability values for the various panels of country groups are cointegrated since the hypothesis of no cointegration is rejected at 1% level of significance with respect to the statistics G_t, G_f and P_t. The findings based on reliable p-values give the evaluated variables a strong proof of the presence of cointegration. We may therefore draw a conclusion that there is a long-term relationship between the variables being studied.

PMG Estimation Results

It is of interest to pin down and determine the long-term and short-term estimates using the PMG estimator via the ARDL model, after ensuring that the variables are cointegrated for the panel of top 10 leading African countries. Table 7 below outlines the summary of the key findings from the PMG estimation approach.

Regarding the long-run coefficients of the estimates, the PMG results reveal that the long-run coefficient of GDP on CO_2 emissions is 0.68 with the standard errors of 0.135 respectively. This implies that the higher the economic growth experience in these selected African countries the higher the increase in carbon emissions thereby, decreasing the quality of environment in the long run. This result does not come as a surprise because different studies in the extant literature have reported that the consequence of economic growth is detrimental to environmental quality.

Among such studies are (Al-mulali *et al*., 2015) who in their study reports in Vietnam increase in economic growth escalates the amount of pollution in the long run. Bah, Abdulwakil, and Azam, (2019) are also on the

Table 5: Results from CADF and CIPS panel unit root test

	$lnco_{2it}$		**$lngdp_{it}$**		**$lnfdi_{it}$**		**$lnfd_{it}$**		**$lnms_{it}$**	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ
CADF	-1.778	-5.034*	-2.152	-3.841*	-3.608	----	-2.592	-4.477	-2.470	-3.157
CIPS	-2.113	-6.341	-1.562	-4.999	-4.126	----	-2.283	-5.833	-0.965	-3.635

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

Table 6: Results from bootstrap panel cointegration test (Westerlund and Edgerton (2007)

Dependent variable $lnco_{2it}$						
Test type	**Statistic**	**Value**	***p*-value**	**Statistic**	**Value**	***p*-value**
Westerlund	G_t	-3.758***	0.000	P_t	-9.911***	0.002
	G_a	-8.921***	0.021	P_a	-9.995	0.387

Note: ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

Table 7: PMG estimation results

Dependent Variable $lnco_{2it}$	Variable	Coefficient	Standard Error	P-Value
Long-run Results				
	$lngdp_{it}$	0.658	0.135	0.000
	$lnfdi_{it}$	- 0.346	0.159	0.030
	$lnfd_{it}$	0.527	0.200	0.008
	$lnms_{it}$	0.518	0.136	0.000
Short-run Results				
	$lngdp_{it}$	0.458	0.080	0.000
	$lnfdi_{it}$	- 0.280	0.098	0.004
	$lnfd_{it}$	- 0.181	0.137	0.188
	$lnms_{it}$	- 0.142	0.045	0.004
	ect_{t-1}	- 0.322	0.076	0.000
Hausman Test Value		2.08		0.588

Note: ***, ** and * designate significance at 1%, 5% as well as 10% statistical level respectively.

opinion that higher rate of economic growth is associated with environmental degradation in Sub-Saharan African countries. On the theoretical side of the literature the study supports the EKC theory that states at the early stage of development economic growth tends to increase the amount of carbon emissions thereby causing environmental degradation.

Foreign investments inflow was found to exert a negative but significant effect on CO_2 emissions. The study further discovered how a 1% increase in FDI could lead to the reduction of CO_2 emissions by 0.34%. This result theoretically supports the pollution halo hypothesis which argues that FDI inflow is capable of enhancing the possibility for ecological sustainability through the transfer of environmentally friendly technology from developed to developing or least developed countries (Rafindadi, Muye, & Kaita, 2018). It also supports the technique effect which states that inflow of foreign investment improves energy efficiency so that producing goods and services generate less pollution to the environment. FDI-induced technique effect could also be realised on the idea of porter hypothesis. Furthermore, FDI creates an avenue for access to foreign capital, which increases income. This, as pointed out earlier can make the society demand for better environmental quality and therefore, low carbon emissions. On the empirical strand of the literature, this result is consistent with studies such as those of (Pazienza, 2015),(Sung, Song, & Park, 2017) and (Hille, Shahbaz, & Moosa, 2019) among others who found that multinational firms in environments with relatively weak regulations use more energy efficient means and are more environmentally conscious than their indigenous counterparts.

In a similar vein, the environmental impact of financial development is positive and significant. A 1% increase in financial development stimulates CO_2 emission by 0.52%. This suggests that financial development worsen the environmental quality through increases in CO_2 emission, the results is in support of the findings of (Charfeddine & Khediri, 2015; Dar & Asif, 2017; Yazdi & Beygi, 2017). The reason for the adverse impact may be that well-developed financial system increases the economic growth which leads to enhance the industrial activities that lead to pollution.

Likewise, the finding support the theoretical view of Schumpeter (1911) theory of finance that states that development of financial sector make funds available to manufactures for manufacturing activities and also to individual consumers, as a result of this economic activities would be enhance that increase the amount of carbon emissions thereby deteriorating the quality of the environment.

Regarding the environmental impact of ICTs, the elasticities of CO_2 emission concerning ICTs is positive and significant, implying that ICT negatively influences environment (increase in the level of CO_2 emission) in emerging economies. The adverse impact of ICT comes from the high energy consumption from the use of many ICT equipment that is not energy efficient. Another possible mechanism is the use of materials for the production and consumption, ICT equipment, energy consumption in daily life directly, short product life cycles and e-waste, and exploitative applications.

The direct use of ICT on the environment is observed through energy consumption and e-waste. Policy measures should take for the advancement of ICT industry which leads to increase the energy efficiency and decrease CO_2 emission. The findings of our study are inconsistent with literature of (Zhang & Liu, 2015; Danish *et al*., 2018a). On the theoretical line of the literature, this finding provides support for the scale effect which tend to suggest that the economy will grow because of ICT, and correspondingly, energy consumption increases will lead to more greenhouse gas emission.

The short-run coefficients on some variables (notably financial development and ICT) tell different stories from the long-run coefficients, though similar effects are seen in the other variables. As explained earlier, short-run coefficients are free from the panel-wide constraint of homogeneity, and for each coefficient there is no single pooled estimate. Nevertheless, given the average of the corresponding coefficients around the panel, the average short-run coefficients can still be studied. As seen in Tables 4, by enforcing the long-run homogeneity constraint, the standard errors of the variables are decreased, and because the PMG methodology enables the definition of the short-run dynamics to differ across tables, it further demonstrates the superiority of the PMG model to that of MG. The average short-run impact for financial development from the PMG estimates indicates a negative and significant effect. In the same way, it is found that ICT has a negative and significant relationship with the amount of carbon emissions, indicating that in the short term, both ICT and financial development tend to improve the environmental quality.

Conclusion and Policy Implication

The need to devise strategies for reducing global warming necessitated awareness of the drivers of carbon emissions. The current work uses heterogeneous empirical approaches of the second generation to examine the effect of economic growth, foreign direct investment, financial development, and ICT on environmental quality for the top 10 leading African countries over the period 1970-2019.

Five financial development metrics were used to advance knowledge about the effect of financial development on environmental quality using PCA in the development of the financial development index. The study further investigates the role of ICT in environmental quality, as most of the previous studies have not considered it, especially in relation to Africa. The findings of this analysis are set out as follows.

The study reveals that economic growth increases the amount of carbon emissions thereby deteriorating the quality of the environment as revealed by the positive and significant coefficients of economic growth. Foreign direct investment on the other hand is found to have a negative relationship with amount of carbon emissions, meaning that increase in the amount of the FDI inflow reduce the amount of carbon emissions, as such improve the quality of the environment. In addition, financial development coefficient appeared to have positive and significant signs, meaning that increase in the development of financial sector degrade the environment by increasing the amount of carbon emissions. Lastly, the development of ICT in Africa according to the result of this study increases the level of carbon emissions as shown by positive and significant coefficient, meaning that the development of ICT activities deteriorate the quality of environment.

Finally, this research not only adds to knowledge but also has significant policy consequences for both the government and the policy makers concerned. Economic growth is positively linked to CO_2 emissions, showing the detrimental impact of economic growth on environmental degradation. Such environmental degradation can affect human health, which eventually decreases productivity and thus affects the rate of economic growth. Therefore, energy-efficient technologies should be applied not only at manufacturing level but also at transport and household levels. The implementation of environmentally sustainable technology would help improve the quality of the environment, increase sustainability in the long term and conserve resources for future generations.

Additionally, efforts must be made to plant trees rather than deforestation for long-term economic growth, and renewable energy sources such as wind, hydropower, and solar power can be used to mitigate emissions. Clear rules will also be enforced to impose a carbon tax and minimum fuel-efficiency requirements on vehicles.

Since FDI inflows are known to boost economic performance and access to foreign capital, and as discovered in this report, environmental quality tends to increase with higher incomes and FDI, it is of paramount importance for African policymakers to encourage the adoption of all those policies that can attract and maintain FDI successfully in their respective and collective climate. Moreover, more foreign capital inflows for the region should only be welcomed, and only if strict adherence to environmental laws is feasible.

In addition, the African countries need to engage in energy efficiency and management and steer their domestic investment policies towards green production processes that will aim to boost energy efficiency in the region. That could be done by following the region's multinational corporations 'manufacturing practices, since they are found to participate in energy-efficient practices. In addition, policy-makers will strive to promote the transition of productive and state-of-the-art technology that can enable rapid transition of environmentally sustainable technologies to the region, thus further reducing their carbon emission rates and creating a cleaner climate.

The study results suggest that the absence of financial development from carbon emission models would contribute to underestimation of real carbon emissions, and that will make mitigation strategies for carbon emissions untenable further. This study recommends that while financial development impedes environmental quality, financial institutions should encourage industries or firms to invest in environmentally friendly projects and offer lower-cost credit to industries or firms dedicated to investing in environmentally sustainable projects. Furthermore, future environmental legislation will make it mandatory for companies/industries to report their environmental results. Environmental policy makers may also use other policy tools to reduce carbon emissions, such as emissions trading or cap and gas emission levy.

Clearly, should such growth in the ICT industry as a whole go unchecked, it may seriously hinder any attempts to mitigate climate change. So, for ICT's carbon emissions, infrastructure is driven primarily by its operating electricity use, while smartphone emissions, on the other hand, are driven primarily by its producing energy and its limited 2-year usage period. The energy of production involves both the extraction of material from the mining activities and the energy consumed during its manufacture. Mitigating measures that could dramatically reduce this unsustainable carbon emissions would include at least I moving to renewable energy for the manufacturing process and, more specifically, extending smartphone service life to 4 years or more.

Nevertheless, the latter may face intense resistance from the manufacturers of telephones for whom the rapid obsolescence of their mobile phones is fundamental to their business model. One way around this is for telecom providers to sell longer service contracts at more competitive reduced rates to enable consumers to retain a much longer span with the same product. Policymakers may also participate in the creation of tax incentives that would push customers to select the longer plans.

Policymakers in those countries will adopt carbon dioxide emission reduction policies. At the other hand, African countries 'governments are required not only to set up renewable energy systems based on geographical and climatic conditions, but also to broaden the renewable energy market through taxation on fossil fuel and incentives (such as discounts, tax exemptions, and feed-in tariffs).

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