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Economic growth and Co2 emissions: Evidence from heterogeneous panel of African countries using bootstrap Granger causality

Delphin Kamanda Espoir¹, Regret Sunge², and Frank Bannor¹

Abstract

The relationship between economic growth and environmental pollution continues to attract undying research interest. While existing studies focused on examining the relationship from growth to pollution or pollution to growth, research on the causal relationship between the two variables is still lacking. This study examined the causal relationship between growth and Co2 emissions across 47 African countries using annual panel data from 1995-2016. Unlike other studies in Africa, the uniqueness of this paper is that we employed the methodology developed by Emirmahmutoğlu and Kose (2011), which considers cross-sectional dependence and slope heterogeneity. The empirical results of the study are as follows: (1) the analysis underpinned a bidirectional causal relationship between growth and Co2 emissions in three countries (Burkina Faso, Mauritania, and the Congo Republic), (2) a unidirectional relationship running from growth to Co2 emissions in seven countries (Niger, Sierra Leone, Angola, Mauritius, Mozambique, Uganda, and Kenya), and (3) a unidirectional relationship running from Co2 emissions to growth in nine countries (Lesotho, Namibia, Tanzania, Egypt, Libya, Chad, Ethiopia, Gabon, and Central African Republic (CAR)). The results also suggested the neutrality hypothesis for the rest of the countries that were not part of these three groups. Henceforth, we provided policy implications based on the four groups' results.

Keywords: Economic development; Environmental pollution; Cross Sectional Dependence; Heterogeneity; Granger Causality; Africa

JEL Code: Q53, Q54, Q56

1. Introduction

As climate change and global warming continue to inflict socio-economic challenges globally, the nexus between greenhouse gas (GHG) emissions and economic growth has moved to the front of the environmental sustainability and development debate. Current deliberations on environmental degradation, climate change and sustainable development are spearheaded by the 2016 Paris Agreement. This is a product of the Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). These policy establishments are geared to guide policy on climate change and development. This is supported by Sustainable Development Goal (SDG) 13 which treats the need to combat climate change and its effects as an urgent matter (United Nations, 2015). Within this domain, dialogue on economic growth and greenhouse emissions, usually proxied by CO2 emissions is topical.

The increased attention reflects the existence of a complicated interdependence and possible trade-off between environmental degradation and economic growth. On one hand, it has been shown that economic growth is positively driven by energy consumption (Chang et al., 2015; Mutascu, 2016; Omay et al., 2014; Tugcu et al., 2012). On the other, energy consumption is known as the major source of greenhouse emission (Royal Society, 2021) which in turn reduces economic growth (Aye & Edoja, 2017; Economist Intelligence Unit (EIU), 2020). The effect of emissions in Africa is projected to be

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relatively severe for two reasons. First, most countries are still developing. As such the demand and consumption for fossil energy and CO₂ emissions are expected to continue an upward trend (Hamilton & Kelly 2017). Second, Africa does not have the required finance to greener technologies and lack effective regulations to reduce energy-related CO₂ emissions (Tajudeen, 2015).

In view of this, we draw attention to the nexus and causality between economic growth and CO₂ in Africa. We appreciate existing related studies on this relationship focusing on Africa, whose evidence is mixed. We note two clusters of studies. The first simply examines the impact of economic growth on CO₂ emissions by testing the Environmental Kuznets (EKC) Hypothesis. The EKC hypothesis is supported by some (including Adzawla et al., 2019; Arouri et al., 2012; Kasperowicz, 2015) and rejected by others (including Abid, 2016; Omotor, 2016; Aye & Edoja, 2017; Demissew Beyene & Kotosz (2020)). One major drawback we pick from these studies is that they impose a unidirectional causality from economic growth to CO₂ emissions and ignore the reverse causality. The second cluster (Chekouri et al., 2021; Dogan et al., 2020; Odhiambo, 2017; Omri et al., 2015; Zaidi & Ferhi, 2019) examines the causality relationship between the two. Findings are diverse mainly according to countries, regions, and econometric estimation techniques. Our contribution in this study stems from the econometric deficiency in the studies examining the causality between economic growth and CO₂ emissions in Africa.

In testing for causality, the studies above did not control for two econometrics problems most likely in panel data analysis³. These are cross-sectional dependence (CD) and slope heterogeneity. It has been emphasised that these issues must be considered in panel causality tests (Emirmahmutoğlu & Kose, 2011; Haghnejad et al., 2020; Bersvendsen & Ditzen, 2021; Espoir & Ngepah, 2021). We posit that testing for CD is compulsory as African countries are increasingly being integrated financially and economically dependent. The ensuing interaction among countries in the region implies that common shocks, technological cross-country spillovers and latent components incorporated into the error term (Espoir and Ngepah, 2021). Accordingly, studies making causality conclusions without controlling for CD are distorted (Herzer & Vollmer 2012). Similarly, it is probable that panel datasets exhibit individual variability in the slopes across cross-sectional units. As such, ignoring this compromises the panel causality tests. Accordingly, the uniqueness of this study is to control for CD and slope heterogeneity in testing the causality between economic growth and CO₂ emissions in Africa. To do this we use the bootstrap panel causality approach by Emirmahmutoğlu and Kose (2011), which is an extension of the time series-based Toda and Yamamoto (1995) Granger causality test.

The rest of the study is structured as follows: Section 2 gives an overview of CO₂ emissions in Africa; section 3 briefs related theoretical and empirical literature on the CO₂-growth nexus. The methodology and estimation techniques are detailed in section 4, results are presented and discussed in section 5 while section 6 concludes and gives recommendations.

2. Overview of CO₂ emissions in Africa

Greenhouse gas (GHG) emission is a major concern all around the world, yet the consequences of its effect on quality of life and climate varies by region (Fayiga, Ipinmoroti & Chirenj, 2018). Carbon Dioxide (CO₂) emissions are often the most significant source of GHG emissions, accounting for around 70% of total GHG emissions (Espoir & Sunge, 2021). While developed nations have

³ The study by Cowan et al. (2012) conducted for BRICS, controlled for these. However, South Africa is the only African country, and such evidence can't be imposed on Africa, especially given that it is a developed country.

dominated historical global CO₂ emissions, emerging economies' rapid increase in energy demand may push their absolute emissions above those of industrialized countries. In 2005, it was estimated that industrialized countries contributed for roughly 40% of global CO₂ emissions, developing countries for about 56%, and aviation and maritime transport accounted for the remaining 4% (Kijewska & Bluszc, 2016). Africa is one of the continents where nearly half of the population does not have access to electricity, and more than 60% of the population still cooks with traditional biomass (International Energy Agency, 2019).

Despite the fact that energy access is a key priority, extending modern energy services in most African countries under a business-as-usual policy scenario would result in significant increases in both primary energy supply and CO₂ emissions by 2030 (Hamilton & Kelly 2017). This is due to the fact that present regulations in many African nations will not be able to avoid such increases in energy-related CO₂ emissions (Tajudeen, 2015). More so, although many electricity-related initiatives focus on large-scale hydropower, natural gas and increasing consumption of oil have become significant contributors of CO₂ emissions. Countries such as Botswana, Kenya, and Senegal, have already witnessed growing emissions, owing mostly to increased coal usage, leading to a 0.7 percent –1% yearly increase in CO₂ emissions (Steckl et al, 2020). More so, in both absolute and per capita terms, Africa's CO₂ emissions from fossil fuels are modest. However, Africa's total carbon emissions have risen twelve-fold since 1950, reaching 311 million metric tons in 2008. Emissions from all fuel sources have increased in the African area over time, with liquid and solid fuels accounting for about 35 percent of total emissions and gas fuels accounting for 16.9% (Boden, Marland, & Andres, 2011).

A limited number of countries are mainly responsible for African emissions from fossil fuels and cement manufacturing. South Africa accounts for 38% of the continental total, while Egypt, Algeria, Nigeria, Libya, and Morocco together account for 46%. Altogether, these six countries have yearly CO₂ emissions above 10 million metric tons. At the same time, four African countries; Libya (2.53), South Africa (2.39), the Seychelles (2.22), and Equatorial Guinea (1.99) have CO₂ emissions per capita that exceed the world average of 1.3 metric ton of carbon per year (Boden, Marland, & Andres, 2011). In addition, emissions from waste disposal in cities in developing countries are expected to grow significantly in the near future, with methane released by dumpsites and landfills accounting for the majority of these emissions (Friedrich & Trois, 2011). Emissions from garbage disposal are projected to represent 8.1 percent of total GHG emissions in Africa (Couth et al., 2011).

While the population of cities is rapidly growing in Africa, with around 54 percent predicted to live in urban areas by 2030 (Antonel & Chowdhury, 2014) - the African continent's fast population growth, industrialisation, and urbanization are not without environmental effects (see figure 1). It can be seen in Figure 1 that there is a co-movement between CO₂ emission and GDP growth from 1981-2016. At the same time, urbanization rate has increased over time. This confirm the Kaya identity - total carbon emissions are influenced by economic growth, the intensity of energy consumption, and population increase (Kaya & Yokoburi, 1997). More so, CO₂ emission in Africa decreased within the 1990 decade but rose steadily albeit variations across the years within the 2000 decade. For the year 2012, CO₂ emission witnessed a significant leap and has increased marginally since then compared with the 1990s. Manufacturing value added has decreased in 1981-2010, but has however, gained a steady, but marginal increase after 2010.

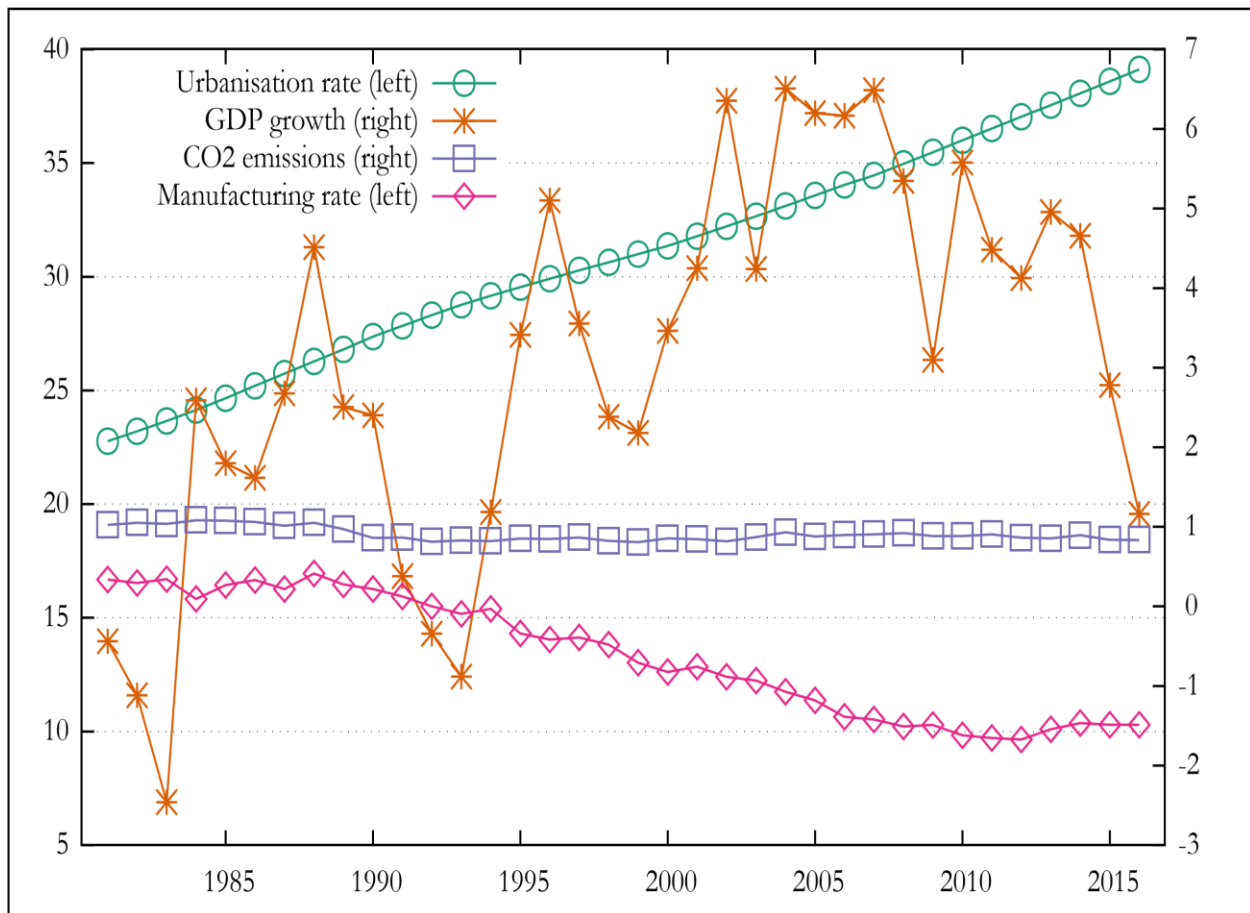


Figure 1: SSA trend of Urbanisation rate, GDP growth, manufacturing value added and Co2 emissions, 1981-2016. Source: Authors' computation using World Bank data

3. Review of the existing literature

In this section, we briefly highlight the theoretical and empirical literature on the causality between economic growth and Co2 emissions. Three strands of literature have emerged. Some studies examined the relationship and causality between (1) energy consumption and economic growth (Balcilar et al., 2010; Chang et al., 2015; Mutascu, 2016; Omay et al., 2014; Tugcu et al., 2012), (2) energy consumption and CO2 emissions (Munir & Khan, 2014; Nugrahanto et al., 2018; Sasana & Putri, 2018; Yu et al., 2015), and (3) Co2 emissions and economic growth (Barassi & Spagnolo, 2012; Chekouri et al., 2021; Odhiambo, 2017; Zaidi & Ferhi, 2019; Wang (2021). Other studies examined all the three relationships (Acheampong, 2018, Saboori et al., 2017, Bhat, 2018, Yusuf et al., 2020). In this paper, we focus on the third strand on the causality between economic growth and Co2 emissions. There is a high volume of literature on this nexus with mixed theoretical positions and evidence. We observe that the heterogeneous nature of findings is according to countries, regions, periods, and econometric methods. Accordingly, policy prescriptions on the matter tends to be idiosyncratic and contradictory.

The causality from economic growth to Co2 emissions is premised on the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis is borrowed from an analysis of the nexus between economic growth and income inequality by Simon Kuznets (1955). It was established that in the initial stages of economic growth, inequality increases up to a certain point, beyond which it falls. Following

the works of Meadows et al. (1972), Jahoda (1973), and Beckerman (1974), the Kuznets hypothesis was first applied in environmental economics by Grossman & Krueger, (1991) and Shafik & Bandyopadhyay (1992). They confirmed an inverted U-shaped association between environmental degradation and economic growth. This finding has been widely accepted as the Environmental Kuznets Curve (EKC) hypothesis. Several arguments have been raised to support the existence of the EKC hypothesis.

According to Lu (2017), in the early stages of economic growth, industrial production depends more on fossil fuel generated energy which emit higher greenhouse emissions. This usually happens in low-income and pre-industrial economies. As growth advances, higher incomes permit investment in production technologies which reduces greenhouse emissions (Stern, 2004; Abid, 2016). This phase is associated with post-industrial high-income economies. However, over the years, the EKC hypothesis has developed into an empirical question. Other recent studies (Adzawla et al., 2019; Arouri et al., 2012; Kasperowicz, 2015) confirm it while others (including Abid, 2016; Omotor, 2016; Aye & Edoja, 2017; Demissew Beyene & Kotosz (2020) reject it. Unlike the causality from economic growth to Co2 emissions, there is no clear theory to explain the reverse causality. However, several reasons have been raised.

The economic growth effects of Co2 emissions are usually linked to the environmental consequences of pollution. Emissions have been the major cause of climate change and global warming (Royal Society, 2021). Globally, mean surface temperature increased by approximately 1°C (1.8°F) since 1900 (Royal Society, 2021). As a result, the global economy has been experiencing environmental imbalance. This has increased the vulnerability of economic growth to persistent floods, cyclones, droughts, diseases, decreases agricultural productivity and food production, and increasing diseases and their spread, among others (Aye & Edoja, 2017). These hazards have cross-cutting adverse effects on economic growth. As the Economist Intelligence Unit (EIU) (2020) reports, climate change effects may lead to a loss of 3% of global gross domestic product (GDP) by 2050, with Africa set to lose more (4.7%).

Some studies only examined the impact of economic growth on Co2 emissions, without checking the possibility of a causality relationship. Jardón et al. (2017) carried a study for 20 Latin American and Caribbean countries over the period 1971-2011. The study revealed inconsistent results. The EKC hypothesis is confirmed when cross-sectional dependence is ignored and rejected otherwise. Yusuf et al.(2020) provides evidence for six African OPEC countries⁴ using data from 1970-2016. Panel autoregressive distributed lag (ARDL) estimations suggest that economic growth has a positive impact on Co2, methane and nitrous oxide emissions. Other recent studies (Abid, 2016; Adzawla et al., 2019) have rejected the EKC hypothesis in Africa. Evidence in support of the EKC hypothesis in Africa has been provided by Omotor (2016) and Demissew Beyene & Kotosz (2020). Although Olubusoye & Musa (2020) show that evidence varies with countries, they reveal that in 79% of the 43 countries, emissions increases with economic growth. This suggests that it is more likely that the EKC is rejected in Africa.

We note that a serious weakness in the studies above is that the unidirectional causality from economic growth to Co2 emissions is presumed. We argue, as in Barassi & Spagnolo (2012), that such an imposition hinders the appropriate interpretation and understanding of the context of the economic growth-Co2 nexus. By just concentrating on testing the EKC hypothesis, these studies ignored the

⁴ Libya, Nigeria, Angola, Algeria, Equatorial Guinea, and Gabon

effect Co2 have on economic growth. We therefore focus more on studies that tests the causality between the two.

Acheampong (2018) provided evidence for the triangular causality relationship. The study used a combination of the panel vector-autoregression (PVAR) and a system-generalized method of moment (System-GMM) estimator on 116 countries using data for the period 1990-2014. The findings are heterogenous across regions. Causality from economic growth to energy consumption could not be established at global and regional levels. Also, elsewhere except the global and Caribbean-Latin America, economic growth was found not to cause carbon emissions. Nonetheless, it was shown that economic growth negatively impacts carbon emissions for the two exceptions. An interesting finding from Sub-Saharan Africa (SSA) is that energy consumption causes economic growth while it negatively causes Co2 emissions. It follows that for SSA, efforts to reduce Co2 emissions through reduction in energy consumption may go against the economic growth agenda.

Barassi & Spagnolo (2012) used linear and non-linear causality tests on data for six developed countries⁵ for the period 1870-2005. The uniqueness of the study is that the causality tests are based on mean and variance spill overs between Co2 emissions and economic growth. The findings suggest strong feedback relationship between the two. More recently, Wang (2021) applied co-integration analysis and Granger causality on the world's top emitters for the period 1990-2015. Causality tests found a uni-directional relationship which changes with the level of development. The direction of causality runs from Co2 emissions to economic growth in developing countries. In developed countries, its runs from economic growth to Co2 emissions.

Several studies have examined the causality relationship between economic growth and Co2 emissions involving regions and countries in Africa. Odhiambo (2017) applied a dynamic-panel Granger-causality approach on data for the period 1986-2013 for 10 SSA countries. Results indicate that there is a unidirectional causal relationship running from economic growth to Co2 emissions in both the short-run and long-run. However, Zaidi & Ferhi (2019) offer different evidence of bi-directional causality evidence for SSA from a dynamic GMM simultaneous-equation estimator for almost the same period, 2000-2012. Dogan et al. (2020) draws our attention to a different dimension in the relationship in Africa. Instead of examining the Co2 causality on economic growth, they did so on total factor productivity. Also, their evidence is not based on linear causality but rather on a nonlinear nonparametric quantile causality approach. The study documents bidirectional causal ordering for nearly all the sample countries.

However, in a related study on Middle East and North African Countries (MENA), Omri et al. (2015) find evidence for bi-directional causality relationship between the two over the period 1990-2011. A study on BRICS countries⁶ by Cowan et al. (2012) suggests that the existence and direction of causality is country specific. The study found causality from GDP to Co2 emissions in South Africa, reverse causality from Co2 emissions to GDP in Brazil, bi-directional causality for Russia and no causality for in India and China. Country evidence is also available for Algeria. Chekouri et al. (2021) employed the wavelet power spectrum (WPS) and Breitung and Candelon (2006) approaches for the period 1971–2018. WPS results suggests co-movement between growth and CO2 emissions while causality tests confirm a one-way causality from growth to CO2 emissions in both the short and long run.

⁵ Canada, France, Italy, Japan, UK and USA

⁶ Brazil, Russia, India, China, and South Africa

4. Estimation strategy and data

4.1. Methodology

Nowadays, panel causality analysis has gained much academic interest in understanding and predicting the causal relationship between two variables. However, several studies (Bersvendsen & Ditzen, 2021; Espoir & Ngepah, 2021) recommend using appropriate econometric methodology that takes into consideration two technical points: cross-sectional dependence (CD) and slope heterogeneity. First, testing for CD before panel causality analysis is now compulsory because the world economies have become more financially and economically integrated in the past three decades. Due to this integration, the econometric literature firmly concluded that panel datasets are likely to present significant CD (Pesaran, 2004). This dependence may happen because of the presence of common shocks, technological cross-country spillovers, integration into common markets, as well as unobserved components that ultimately form part of the error term (Espoir & Ngepah, 2021). Failing to account for cross-sectional dependence could lead to spurious causality results if the errors ($\varepsilon_{i,t}$), are not independent across units (Herzer & Vollmer 2012). Second, concerning slope heterogeneity, panel data methodologies estimate variations in between cross-sectional units by fixed constants (using fixed and random effects technique). However, some panel datasets exhibit individual variability in the slopes across cross-sectional units. Overlooking this variability may bias the causal relationship results and cause incorrect inference (Chang et al, 2015; Bersvendsen & Ditzen, 2021). Henceforth, this study examines the issue of cross-sectional dependence and slope heterogeneity before investigating the causality between economic growth and Co2 emissions.

4.1.1. Testing cross-sectional dependence

To test for CD among the variables, several studies have employed the Lagrange multiplier (LM hereafter) procedure developed by Breusch and Pagan (1980). In this study, we used three different CD tests: the chi-squared distributed test developed by Friedman (1937), the Q distribution (T -asymptotically distributed) test suggested by Frees (1995), and the standard normal distribution test recently developed by Pesaran (2004). While the Pesaran (2004) and Frees (1995) tests are applied as the main tests, the Friedman (1937) test was employed for robustness check. Also, note that the Frees (1995) test is an improved versions of a Lagrange Multiplier test statistic due to Breusch and Pagan (1980). Consider the following standard panel model:

$$Y_{i,t} = \mu_i + \xi_i \varepsilon_{i,t} \quad (1)$$

Where $Y_{i,t}$, $T = 1, 2, \dots, T$, are observations from the i th experimental unit. $\varepsilon_{i,t}$ are unobservable random variables and assumed to be identically and independently distributed. μ_i is either a fixed or random effects.

Using the specification in Eq. (1), Breusch and Pagan (1980) developed a LM statistic for CD test that can be presented as:

$$C_{AVE}^2 = \binom{n}{2}^{-1} \sum_{i < j} c_{i,j}^2 \quad (2)$$

where $c_{i,j} = a_{i,j} / (a_{i,j} a_{j,j})^{1/2}$ is the Pearson coefficient of correlation between the i^{th} and j^{th} units.

Breusch and Pagan (1980) indicated that, as $T \rightarrow \infty$, the limiting distribution $(T - 1) \binom{n}{2} C_{AVE}^2$ is χ^2 with $n(n - 1)/2$ degrees of freedom. A standard version was also obtained by subtracting the

asymptotic mean and dividing by the asymptotic standard deviation ($C_{STD} = n((T-1)C_{AVE}^2 - 1)/2$). The authors showed that statistic of the standard version has an asymptotic standard normal distribution (as $T \rightarrow \infty$ first, then as $N \rightarrow \infty$). However, in the case where $N \rightarrow \infty$ and T is fixed (in other words, the cross-section units are large than the time dimension), the finite, and even the limiting, distribution of C_{STD} is not distribution-free. To obtain a statistic that is distribution-free, Frees (1995) proposed using a nonparametric version of C_{AVE}^2 , which is presented as:

$$R_{AVE}^2 = \binom{n}{2}^{-1} \sum_{i < j} r_{i,j}^2 \quad (3)$$

where $r_{i,j}$ is the Spearman rank coefficient of correlation between the i^{th} and j^{th} units. The definition of $r_{i,j}$ is as follows. $r_{i,j} = p_{i,j} / (p_{i,j} p_{j,j})^{1/2}$, where $p_{i,j} = (T-1)^{-1} X \sum_i \left(R_{i,t} - \frac{T+1}{2} \right) \left(R_{j,t} - \frac{T+1}{2} \right)$ and $\{R_{i,1}, R_{i,2} \dots R_{i,T}\}$ are the ranks of $\{Y_{i,1}, Y_{i,2} \dots Y_{i,T}\}$.

However, the CD test is subject to decreasing power when the population average pair-wise correlations are zero. This is also valid even if the underlying individual population pair-wise correlations are non-zero (Pesaran et al., 2008). To address this problem, Pesaran et al. (2008) suggested a bias-adjusted CD test, which is a modified version of the LM test. The bias-adjusted LM test is presented as:

$$LM_{adj} = \sqrt{\left(\frac{2T}{N(N-1)} \right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{i,j} \frac{(T-K)\hat{\rho}_{i,j}^2 \mu_{Ti,j}}{\sqrt{V_{Ti,j}^2}} \quad (4)$$

where $\mu_{Ti,j}$ and $V_{Ti,j}^2$ are respectively the exact average and variance of the term $(T-K)\hat{\rho}_{i,j}^2$, (for more details see Pesaran et al., 2008). Under the null hypothesis of cross-sectional independence with first $T \rightarrow \infty$ first, then as $N \rightarrow \infty$, the LM_{adj} is asymptotically distributed as standard normal.

4.1.2. Testing slope homogeneity

We have also investigated whether or not the slope coefficients are homogeneous across panel units. We employed the standard delta test ($\tilde{\Delta}$) proposed by Pesaran and Yamagata (2008). This test is based on a standardised version of Swamy's (1970) test. The Swamy's (1970) test requires panel data models where N is small relative to T , while the Pesaran and Yamagata (2008) test analyses slope homogeneity in large panels where N and $T \rightarrow \infty$. For the $\tilde{\Delta}$ test, Pesaran and Yamagata (2008) proposed two main steps to be used to obtain the test statistic. First, the authors suggested to compute the modified version of Swamy's test as:

$$\tilde{S} = \sum_{i=1}^N \left((\hat{\beta}_i - \tilde{\beta}_{WFE}) \frac{X_i' M_\tau X_i}{\tilde{\sigma}_i^2} (\hat{\beta}_i - \tilde{\beta}_{WFE}) \right) \quad (5)$$

where $\hat{\beta}_i$ and $\tilde{\beta}_{WFE}$ are vectors of coefficients from pooled OLS and weighted fixed effect pooled estimator, respectively. $\tilde{\sigma}_i^2$ is the estimator of σ_i^2 and M_τ is an identity matrix. Using Swamy's statistic from Eq. (5), the standard delta statistic is developed as:

$$\tilde{\Delta} = \sqrt{N} \left(\frac{N^{-1} \tilde{S} - K}{\sqrt{2k}} \right) \quad (6)$$

Under the null hypothesis of slope homogeneity with the condition of $(N, T) \rightarrow \infty$ so long as \sqrt{N}/T , the $\tilde{\Delta}$ test has asymptotic standard normal distribution ($\varepsilon \sim N(0, \sigma^2)$). Furthermore, for the small sample properties, the $\tilde{\Delta}$ test can be improved under the same condition of normally distributed errors through a bias adjusted version as:

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1} \tilde{S} - E(\tilde{Z}_{i,t})}{\sqrt{\text{Var}(\tilde{Z}_{i,t})}} \right) \quad (7)$$

where the mean $E(\tilde{Z}_{i,t}) = k$ and the variance $\text{Var}(\tilde{Z}_{i,t}) = \frac{2K(T-k-1)}{T+1}$

In the presence of cross-sectional dependence and slope heterogeneity, testing panel causality between growth and Co2 emissions by an econometric technique that imposes homogeneity restrictions and does not consider the spatial interaction effects might result in inaccurate results. Consequently, this study used the bootstrap panel causality approach, given the positive evidence of the existence in our sample group of the two technical issues discussed in this section.

4.1.3. Panel Granger causality analysis

We analysed the bidirectional causal relationship between economic growth and Co2 emissions using Granger causality test in heterogeneous mixed panels as developed by Emirmahmutoğlu and Kose (2011). This test is the panel version of the traditional Toda and Yamamoto (1995) Granger causality test in time series. The test makes it possible to assess panel causality between two variables by taking into account cross-sectional heterogeneity without having to examine whether the time series of units in the panel are non-stationary. Spatial dependence is also taken into consideration in this framework, as the critical values of panel statistics are computed using Monte Carlo simulations. Therefore, to test for Granger causality in heterogeneous mixed and cross-sectional dependent panels, a level Lag Augmented Vector Autoregressive (LA-VAR) model with $q_i + d \max_i$ is specified as follows:

$$x_{i,t} = \varphi_i^x + \sum_{j=1}^{q_i+d \max_i} B_{11,ij} x_{i,t-j} + \sum_{j=1}^{q_i+d \max_i} B_{12,ij} y_{i,t-j} + v_{i,t}^x \quad (8)$$

$$y_{i,t} = \varphi_i^y + \sum_{j=1}^{q_i+d \max_i} B_{21,ij} x_{i,t-j} + \sum_{j=1}^{q_i+d \max_i} B_{22,ij} y_{i,t-j} + v_{i,t}^y \quad (9)$$

where q_i is the lag order of the VAR system and $d \max_i$ is the maximal order of integration considered to be obtained in the VAR system for each unit i .⁷ We tested the causality from x to y (that is, from lnGDPPC to lnCo2) in Eq. (8). We applied the same procedure to testing causality from y to x (from lnCo2 to lnGDPPC) in Eq. (9). As in Emirmahmutoğlu and Kose (2011), we employed the traditional Dickey and Fuller (1981) unit root test in order to determine the maximal order of integration ($d \max_i$) of the two variables of interest in the VAR system for each country.

Emirmahmutoğlu and Kose (2011) showed that a robust test of no causality in the null hypothesis requires a slight transformation of equation (8) and (9). For instance, the authors propose to rewrite equation (9) by OLS under the null hypothesis of no causality ($B_{21,i1} = \dots = B_{21,iq_i} = 0$) and determine the residuals for each unit as follows:

⁷ The lag order is automatically obtained via Schwarz information criteria (SBC) or Akaike information criteria (AIC) by starting $q_i = 8$.

$$\hat{v}_{i,t}^y = y_{i,t} - \hat{v}_i^y - \sum_{j=q_i+1}^{q_i+d \max_i} \hat{B}_{21,ij} x_{i,t-j} - \sum_{j=1}^{q_i+d \max_i} \hat{B}_{22,ij} y_{i,t-j} \quad (10)$$

Moreover, the residuals in Eq. (10) are centered as suggested by Stine (1987) as follows:

$$\tilde{v}_t = \hat{v}_t - (T - q - h - 2)^{-1} \sum_{t=q+h+2}^T \hat{v}_t \quad (11)$$

where $\hat{v}_t = (\hat{v}_1, \hat{v}_2 \dots \hat{v}_{NT})'$, $q = \max q_i$ and $h = \max d \max_i$. Finally, a bootstrapping sample is constructed to test the null hypothesis using the following equation:

$$y_{i,t}^* = \hat{v}_i^y + \sum_{j=q_i+1}^{q_i+d \max_i} \hat{B}_{21,ij} x_{i,t-j} - \sum_{j=1}^{q_i+d \max_i} \hat{B}_{22,ij} y_{i,t-j}^* + \tilde{v}_{i,t}^* \quad (12)$$

where \hat{v}_i^y , $\hat{B}_{21,ij}$ and $\hat{B}_{22,ij}$ are estimates from equation (10) and $\tilde{v}_{i,t}^*$ are bootstrap residuals. We now substitute $y_{i,t}^*$ for $y_{i,t}$ and estimate Eq. (9). Finally, cross-country Wald statistics were calculated to test the null hypothesis of granger no causality against an alternative of Granger causality. Using individual p-values(p_i) that correspond to the Wald statistic of the i^{th} individual cross-section, the Fisher (1932) statistic λ is obtained as follows:

$$\lambda = -2 \sum_{i=1}^N \ln p_i \quad i = 1, 2, \dots, N \quad (13)$$

where p_i is the p-value corresponding to the Wald statistic of the i^{th} individual cross-section. Emirmahmutoğlu and Kose (2011) demonstrate that the performance of LA-VAR approach under both cross-sectional independence and cross-sectional dependence are satisfactory for the entire values of T and N .

4.2. Data

In examining the panel causality between economic growth and Co2 emissions across 47 African countries, this study used annual time-series data that covers the period 1995-2016. The variables employed are GDP per capita and Co2 emissions per capita. Real GDP per capita is measured in constant 2005 dollars, and the time series were collected from the World Development Indicator (WDI) of the World Bank (2021). The Co2 emissions per capita data employed is measured in metric tonnes and is based from carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. This time-series data was collected from WDI of the World bank (World Bank data, 2021). For panel causality analysis, all the two variables were used in natural logarithm form. Table 1 and 2 present the descriptive statistics of the two variables of concern for each of the 47 African countries included in our sample group. By looking at the descriptive in these tables, we find that Seychelles and Burundi have the highest and lowest mean of GDP per capita respectively, and that South Africa and the Democratic Republic of Congo (DRC) have the highest and lowest mean of Co2 per capita respectively. Figure 2 presents more details about per country trends between GDP and Co2 emissions per capita and Table 3 provide the list of countries (see Appendix).

Table 1: Summary statistics of GDP per capita for African countries

Country	Gdp per capita (in USD)						Country	Gdp per capita (in USD)					
	Mean	Min	Max	Std. Dev	Skewness	Kurtosis		Mean	Min	Max	Std. Dev	Skewness	Kurtosis
Benin	819.174	361.1	1291.41	316.719	-0.152	1.560	Namibia	3678.797	1769.1	5942.21	1397.378	0.130	1.569
Burkina Faso	485.956	229.4	792.84	206.941	0.125	1.463	Seychelles	10396.52	6583.2	15068.62	2815.81	0.299	1.832
Cape Verde	2410.711	1213.6	3740.38	1015.625	0.045	1.274	South Africa	4983.338	2502.2	8007.47	1689.45	0.111	1.790
Côte d'Ivoire	1082.561	651.3	2013.38	386.005	1.124	3.523	Tanzania	581.472	182.3	1030.09	259.719	0.314	1.892
Gambia	672.409	335.9	924.50	133.863	-0.647	3.802	Zambia	938.448	335.7	1878.91	561.507	0.312	1.531
Ghana	945.773	258.4	2345.39	665.562	0.607	2.010	Zimbabwe	793.195	356.6	1464.58	385.502	0.791	2.052
Guinea	553.372	322.4	787.23	162.028	0.032	1.464	Egypt	1957.543	965.1	3562.93	940.218	0.623	1.747
Guinea-Bissau	442.830	178.8	703.66	169.942	-0.086	1.603	Burundi	188.022	113.5	305.5	59.854	0.543	1.883
Mali	531.634	267.1	848.27	220.131	0.102	1.367	Rwanda	445.453	221.6	751.63	208.567	0.389	1.441
Niger	363.344	197.3	564.59	131.106	0.198	1.384	Libya	7529.584	3703.0	14382.58	3115.305	0.768	2.392
Nigeria	1517.211	408.1	3098.98	950.010	0.224	1.518	Chad	572.547	165.7	1020.28	330.226	-0.029	1.306
Senegal	1014.215	604.6	1411.92	309.413	-0.060	1.313	Tunisia	3230.901	1975.9	4307.15	880.016	-0.094	1.348
Sierra Leone	353.967	138.6	716.83	174.499	0.738	2.547	Algeria	3266.616	1452.2	5591.21	1536.158	0.226	1.539
Togo	447.865	292.5	640.93	119.746	0.207	1.481	Morocco	2200.687	1334.9	3171.69	708.479	0.037	1.287
Angola	2404.918	387.7	5408.4	1837.629	0.282	1.550	Mauritania	1192.061	639.6	1892.09	441.621	0.214	1.513
Botswana	5160.509	3039.9	7780.65	1689.312	0.088	1.530	Uganda	489.479	239.4	879.72	255.974	0.484	1.385
Comoros	1079.739	645.8	1513.83	302.146	-0.059	1.490	Equatorial Guinea	10006.62	285.5	22942.58	8317.051	0.201	1.478
DRC	281.725	102.5	497.31	133.646	0.281	1.620	Kenya	740.983	325.7	1410.52	365.766	0.518	1.792
Eswatini	2848.104	1405.4	4527.66	1084.613	0.077	1.560	Ethiopia	280.660	111.9	717.12	190.613	0.938	2.617
Lesotho	804.161	382.1	1308.69	318.748	0.128	1.547	Gabon	6761.025	3831.7	10809.65	2373.232	0.235	1.626
Madagascar	397.806	279.9	541.06	98.991	0.224	1.402	Cameroon	1057.47	649.9	1542.62	310.745	0.014	1.405
Malawi	304.113	141.9	534.95	109.152	0.187	2.383	Congo, Republic of	1970.581	660.4	3922.86	1141.364	0.448	1.803
Mauritius	6297.481	3593.2	10153.94	2449.705	0.289	1.466	C Africa Rep	367.405	250.3	565.80	95.318	0.617	2.352
Mozambique	431.606	183.6	673.97	145.905	0.233	1.915							

Table 2: Summary statistics of Co2 per capita for African countries

Country	Co2 emissions per capita (in metric tonnes)						Country	Mean	Min	Max	Std. Dev	Skewness	Kurtosis
	Mean	Min	Max	Std. Dev	Skewness	Kurtosis							
Benin	0.389	0.187	0.595	0.147	-0.058	1.291	Namibia	1.248	0.915	1.793	0.277	0.639	2.025
Burkina Faso	0.112	0.062	0.183	0.039	0.609	1.940	Seychelles	5.974	2.629	8.936	1.820	-0.117	2.066
Cape Verde	0.784	0.313	1.234	0.295	-0.308	1.610	South Africa	8.853	7.727	9.979	0.554	0.394	2.927
Côte d'Ivoire	0.414	0.282	0.534	0.065	-0.208	2.266	Tanzania	0.141	0.077	0.251	0.056	0.569	2.041
Gambia	0.219	0.186	0.253	0.019	0.161	2.233	Zambia	0.214	0.154	0.314	0.044	0.793	2.452
Ghana	0.410	0.310	0.594	0.097	0.886	2.253	Zimbabwe	0.925	0.447	1.339	0.253	0.133	2.141
Guinea	0.214	0.177	0.266	0.024	0.580	2.542	Egypt	2.160	1.480	2.572	0.364	-0.459	1.793
Guinea-Bissau	0.154	0.122	0.178	0.014	-1.312	4.126	Burundi	0.034	0.020	0.047	0.008	-0.319	1.654
Mali	0.102	0.049	0.181	0.043	0.586	1.938	Rwanda	0.068	0.056	0.095	0.009	1.001	3.493
Niger	0.069	0.049	0.106	0.018	0.928	2.379	Libya	8.757	6.355	9.997	0.696	-1.748	7.846
Nigeria	0.611	0.312	0.808	0.166	-0.896	2.220	Chad	0.069	0.056	0.083	0.009	-0.045	1.540
Senegal	0.496	0.357	0.729	0.119	0.714	2.121	Tunisia	2.243	1.723	2.705	0.294	-0.183	1.955
Sierra Leone	0.122	0.089	0.186	0.025	0.963	3.199	Algeria	3.225	2.677	3.854	0.340	0.052	2.034
Togo	0.298	0.211	0.445	0.072	0.516	1.853	Morocco	1.468	1.100	1.783	0.262	-0.206	1.386
Angola	0.974	0.475	1.664	0.346	-0.031	1.856	Mauritania	0.559	0.446	0.746	0.099	0.451	1.800
Botswana	2.300	1.818	3.283	0.347	1.153	4.377	Uganda	0.088	0.046	0.143	0.032	0.251	1.517
Comoros	0.198	0.154	0.257	0.033	0.287	1.804	Equatorial Guinea	6.026	0.169	11.204	3.847	-0.462	1.774
DRC	0.033	0.016	0.063	0.012	0.768	2.873	Kenya	0.286	0.194	0.365	0.044	-0.217	2.425
Eswatini	1.079	0.823	1.403	0.130	0.481	3.277	Ethiopia	0.077	0.044	0.143	0.028	1.120	3.305
Lesotho	1.032	0.898	1.210	0.116	0.220	1.477	Gabon	3.352	2.649	4.289	0.594	0.375	1.598
Madagascar	0.109	0.073	0.156	0.021	0.666	2.663	Cameroon	0.260	0.203	0.346	0.050	0.499	1.682
Malawi	0.078	0.064	0.093	0.007	0.682	2.610	Congo, Republic of	0.444	0.173	0.817	0.192	0.360	1.686
Mauritius	2.659	1.630	3.442	0.579	-0.435	1.885	Central Africa Rep	0.065	0.058	0.074	0.005	0.391	1.825
Mozambique	0.121	0.067	0.320	0.070	1.814	5.126							

5. Empirical results

Following the methodological procedure discussed in this study, we started primarily by testing for cross-sectional dependence and slope homogeneity across the panel units. In so doing, the study employed three different tests ($CD_{Pesaran}$, CD_{Frees} , and $CD_{Friedman}$) to examine the existence or not of cross-sectional dependence, with the null hypothesis of cross-sectional independence. The three tests were performed on the residuals of the fixed effects regression, where the log of Co2 per capita is the dependent variable and GDP per capita is the independent variable. The results of this analysis are presented in Table 4. As can be seen from this table, the $CD_{Pesaran}$ and $CD_{Friedman}$ test statistic reject the null hypothesis at the 1% level of significance, while the CD_{Frees} statistic failed to reject the null. By the law of the majority, we concluded that there is evidence of cross-sectional dependence. This finding implies that an economic and financial shock originating from one country may produce spatial spillover effects in neighboring countries. Henceforth, the causality test employed to investigate the causal relationship between GDP and Co2 per capita controlled for this dependence.

Table 4: Results of Cross-sectional dependence and slope homogeneity tests.

Test	Statistic	Probability	Critical values from Frees' Q distribution		
			$\alpha = 1\%$	$\alpha = 5\%$	$\alpha = 10\%$
$CD_{Pesaran}$	3.163***	0.0016			
CD_{Frees}	38.888	0.7621			
$CD_{Friedman}$	6.522***	---	0.2225	0.1537	0.1174
$\tilde{\Delta}$	23.177***	0.0000			
$\tilde{\Delta}_{adj}$	28.069***	0.0000			
Swamy-Shat	1.7e+05***	0.0000			

Note: (1) *, ** and *** indicate significance at the 10, 5 and 1% levels of significance respectively (inside this Table, only*** statistical significance at the 1% level is concluded). (2) The cross-sectional dependence and slope homogeneous tests are performed based on the panel model that includes the log of Co2 emissions as the dependent variable and log of GDP per capita as the independent variable.

Regarding slope homogeneity across the panel units, we performed three different tests ($\tilde{\Delta}$, $\tilde{\Delta}_{adj}$, and Swamy-Shat) presented in Table 4. As can be observed from this table, the statistic of the three tests rejects the null hypothesis of slope homogeneity at the 1% level of significance across all the panel units. This signifies that panel causality analysis by assuming slope homogeneity restrictions may provide inaccurate inferences and misleading results. Thus, our study took into account countries specific characteristics in analysis panel causality.

Given the positive evidence of cross-sectional dependence and slope heterogeneity across the African countries in relation to economic development and pollution, the results suggest the suitability of the bootstrap panel causality framework as developed by Emirmahmutoğlu and Kose (2011). As discussed earlier in the methodology section, this panel causality test is developed on meta-analysis of Fisher (1932) in heterogeneous mixed panels and account for the two econometric issues. The results of our bootstrap panel causality analysis are presented in table 5.

Overall, the results in Table 5 indicate that both null hypothesis of “Granger no causality from lnGDPPC to lnCo2 and “Granger no causality from lnCo2 to lnGDPPC” cannot be rejected even at the 10% significance level for 41 and 39 countries, respectively. Note that the bootstrap regression was performed using the Bayesian Swartz Information Criteria (BSIC) for lag length selection (q_i). Under BSIC, the fisher test statistic (187.03) was found greater than all the bootstrap critical values for growth-led hypothesis.

Table 5: Results of bootstrap Granger causality test using BSIC selection criteria

Country	q_i	Growth-led hypothesis		Co2-led hypothesis		
		Wald statistic (W_i)	p-value (p_i)	Wald statistic (W_i)	p-value (p_i)	
Benin	1	0.002	0.967	0.002	0.963	
Burkina Faso	5	18.960***	0.002	15.647***	0.008	
Cabo Verde	1	0.088	0.767	0.009	0.926	
Côte d'Ivoire	1	0.065	0.799	0.059	0.809	
Gambia	1	0.482	0.487	0.001	0.973	
Ghana	1	0.040	0.841	0.015	0.902	
Guinea	5	4.347	0.501	9.824*	0.080	
Guinea-Bissau	1	0.004	0.950	0.000	0.990	
Mali	5	0.833	0.975	7.767	0.170	
Niger	1	6.716***	0.010	4.168**	0.041	
Nigeria	5	7.548	0.183	2.196	0.821	
Senegal	1	2.033	0.154	0.000	0.982	
Sierra Leone	5	17.409***	0.004	0.704	0.983	
Togo	1	0.041	0.840	0.092	0.762	
Angola	1	6.346***	0.012	0.670	0.413	
Botswana	1	0.005	0.946	0.029	0.864	
Comoros	1	0.753	0.385	2.265	0.132	
DRC	1	0.033	0.857	0.033	0.857	
Eswatini	5	1.943	0.857	0.634	0.986	
Lesotho	5	2.010	0.848	38.416***	0.000	
Madagascar	1	0.002	0.965	0.001	0.970	
Malawi	1	0.003	0.955	0.004	0.952	
Mauritius	5	11.561**	0.041	7.591	0.180	
Mozambique	1	3.557**	0.059	3.089	0.079	
Namibia	5	3.908	0.563	22.101***	0.001	
Seychelles	1	0.069	0.792	0.069	0.793	
South Africa	1	0.105	0.746	0.098	0.754	
Tanzania	5	8.990	0.109	9.415*	0.094	
Zambia	1	0.022	0.883	0.018	0.894	
Zimbabwe	1	0.054	0.816	0.056	0.814	
Egypt	5	0.330	0.997	11.988***	0.035	
Burundi	1	0.262	0.609	0.255	0.613	
Rwanda	5	1.418	0.922	1.233	0.942	
Libya	5	1.277	0.937	70.120***	0.000	
Chad	1	0.406	0.524	6.789***	0.009	
Tunisia	1	0.136	0.712	0.163	0.686	
Algeria	1	0.132	0.717	0.075	0.785	
Morocco	1	0.044	0.834	0.007	0.931	
Mauritania	5	33.872***	0.000	11.138**	0.049	
Uganda	5	22.330***	0.000	0.900	0.970	
Equatorial Guinea	1	0.011	0.918	0.007	0.931	
Kenya	5	10.584*	0.060	4.721	0.451	
Ethiopia	5	0.297	0.998	11.030***	0.051	
Gabon	1	0.163	0.687	2.862*	0.091	
Cameroon	1	0.010	0.921	0.005	0.946	
Congo, Republic of	1	3.844**	0.050	2.840*	0.092	
CAR	1	1.983	0.159	8.028***	0.005	
Fisher test statistic (λ):	187.953			206.008		
	CV1%	CV5%	CV10%	CV1%	CV5%	CV10%
	187.037	160.584	147.570	185.150	158.188	145.670

Note: Selection of Lag orders q_i are done automatically by minimizing the Schwarz Bayesian Information Criteria. ***, **, *, indicate significance at the 1, 5 and 10% level, respectively.

On the other hand, the fisher test statistic (206.008) was found greater than all the bootstrap critical values for the Co2-led hypothesis. This finding indicated that there is bidirectional causality between GDP and Co2 emissions per capita.

Furthermore, the calculated Wald statistics as well as p-values suggested strong evidence against the null hypothesis “Granger no causality from lnGDPPC to lnCo2” at the 10% level of significance for Kenya. As for Congo, Republic of, Mauritius and Mozambique, the results suggested evidence against the null hypothesis “Granger no causality from lnGDPPC to lnCo2” at the 5% level of significance, while the null hypothesis in the case of Burkina Faso, Niger, Sierra Leone, Angola, Mauritania, and Uganda, was rejected at the 1% level of significance. Economic growth appears to exercise a significant effect on Co2 emissions in ten African countries. On the other hand, the calculated Wald statistics as well as p-values suggested strong evidence against the null hypothesis “Granger no causality from lnCo2 to lnGDPPC” at the 10% level of significance for Guinea, Mozambique, Tanzania, Gabon and Congo Republic. In the case of Niger and Mauritania, the results indicated evidence against the null hypothesis “Granger no causality from lnCo2 to lnGDPPC” at the 5% level of significance, while the null hypothesis in the case of Burkina Faso, Lesotho, Namibia, Egypt, Libya, Chad, Mauritania, Ethiopia and CAR, was rejected at the 1% level of significance. According to this finding, Co2 emissions seem to exercise a significant effect on economic growth in fourteen African countries.

Table 6 summarizes the results of the bootstrap panel causality analysis from the findings reported in Table 5. The results in Table 6 are those of the three categories where there is at least one variable determining the other. Countries that are not included in Table 6 are those where the hypothesis of neutrality was confirmed. The results of the first category indicated a unidirectional effect from economic growth to Co2 emissions in seven countries (unidirectional causality), without any feedback effect from Co2 emissions to growth. This implies that policies defined to increase production in those countries should be taken with extreme caution as they may accelerate the deterioration of the environment.

Table 6: Summary of bootstrap panel causality findings

Country	Growth-led hypothesis	Co2-led hypothesis	Direction of causality	Conclusion for causality
Burkina Faso	✓	✓	GDPPC↔Co2	Bidirectional
Niger	✓	X	GDPPC→Co2	Unidirectional
Sierra Leone	✓	X	GDPPC→Co2	Unidirectional
Angola	✓	X	GDPPC→Co2	Unidirectional
Mauritius	✓	X	GDPPC→Co2	Unidirectional
Mozambique	✓	X	GDPPC→Co2	Unidirectional
Mauritania	✓	✓	GDPPC↔Co2	Bidirectional
Uganda	✓	X	GDPPC→Co2	Unidirectional
Kenya	✓	X	GDPPC→Co2	Unidirectional
Congo Republic, of	✓	✓	GDPPC↔Co2	Bidirectional
Lesotho	X	✓	GDPPC←Co2	Unidirectional
Namibia	X	✓	GDPPC←Co2	Unidirectional
Tanzania	X	✓	GDPPC←Co2	Unidirectional
Egypt	X	✓	GDPPC←Co2	Unidirectional
Libya	X	✓	GDPPC←Co2	Unidirectional
Tchad	X	✓	GDPPC←Co2	Unidirectional
Ethiopia	X	✓	GDPPC←Co2	Unidirectional
Gabon	X	✓	GDPPC←Co2	Unidirectional
CAR	X	✓	GDPPC←Co2	Unidirectional

The second category of results suggested a unidirectional effect running from Co2 emissions to growth in nine countries, without any feedback effect from economic growth to Co2 emissions. This finding also indicates that environmental policies aimed to increase production may not have a significant effect on Co2 emissions, while those defined to reduce Co2 emissions may significantly hurt growth in those countries. The third category results suggested bidirectional effects from economic growth to Co2 emissions and then from Co2 emissions to growth in three countries. This finding implies that environmental policies specifically designed to reduce Co2 emissions may significantly impact production, while growth-accelerating policies may dramatically increase the stock of Co2 emissions in those countries. Finally, the fourth category results suggested no causal relationship between growth and Co2 emissions. The implication of this finding is that programmes that will promote GHG emissions reductions will not hurt the current economic growth momentum in this category of countries. Meanwhile, if all the existing economic and health conditions remain unchanged, the current economic production levels in this category of countries will not substantially lead to more Co2 emissions. Given that the neutrality hypothesis holds for most countries within our sample, there may be a tendency for those countries to economically grow, especially during post Covid-19 period. The possible economic growth may result to more Co2 emissions if countries fail to embark into energy transition by simultaneously invest in green technologies. However, while a few numbers of countries in Africa have been observed to be embarking in energy transition from the nonrenewable to renewable energy sources (Federal Ministry of Economic Cooperation and Development, 2020), the majority are still engaging into the nonrenewable energy sources possibly due to low or lack of enough resources. Therefore, as low resources countries strive to achieve high economic development, all things remain equal, Co2 emissions is going to increase. To achieve the Paris agreement on climate change through lowering Co2 emissions, the advanced economies should commit in supporting less-developed economies in the quest to achieving energy transition without harming their economic expansion ambitions.

6. Conclusion

This study examined the causal relationship between growth and Co2 emissions across 47 African countries using annual panel data from 1995-2016. The study controlled for Cross-sectional (CD) and slope heterogeneity in testing the causality between growth and Co2 emissions in Africa. Specifically, we employed the bootstrap panel causality approach by Emirmahmutoglu and Kose (2011), which account for the two econometrical issues. Testing for CD before panel causality analysis is imperative because, since the past three decades, world economies have become more financially and economically integrated, of which Africa is no exception. Due to this integration, panel datasets are likely to present significant cross-sectional dependency. This dependence may happen because of the presence of common shocks, technological cross-country spillovers, integration into common markets, as well as unobserved components that ultimately form part of the error term. Accounting for CD help us to avoid spurious causality results if the errors are not independent across units. Also, controlling for slope heterogeneity eliminates incorrect inference resulting from bias causal relationship within the results.

The empirical results of the study revealed four (4) main categories of findings. First, there is a unidirectional relationship running from growth to Co2 emissions without any feedback effect from Co2 emissions to growth in seven countries (Niger, Sierra Leone, Angola, Mauritius, Mozambique, Uganda, and Kenya). The confirmation of a unidirectional relationship for those countries shows that any stratagem geared toward boosting output should be approached with great caution, since it may hasten the deterioration of the ecosystem. Second, a unidirectional effect running from Co2 emissions to growth without any feedback effect from economic growth to Co2 emissions was found in nine

countries (Lesotho, Namibia, Tanzania, Egypt, Libya, Chad, Ethiopia, Gabon, and Central African Republic (CAR). In those countries, policies targeted at increasing output may have little influence on Co2 emissions, but methods aiming at reducing Co2 emissions may have a major impact on growth. Third, a bidirectional effect from economic growth to Co2 emissions and then from Co2 emissions to growth was seen in three countries (Burkina Faso, Mauritania, and the Congo Republic). For those countries, environmental policies aimed at reducing Co2 emissions may have a major influence on output, while growth-promoting policies may considerably increase the stock of Co2 emissions at the same time. Lastly, the results also provided evidence of the neutrality hypothesis for 27 African countries. The presence of the neutrality hypothesis implies that Co2 emissions and growth indicators are unrelated for the majority of the countries in our sample group.

Given the implications of this study's findings, we recommended that in the interest of the Paris agreement on climate through Co2 emissions reductions below the pre-industrial level, the more advanced economies should commit in supporting African economies in the quest to achieving energy transition without harming their economic expansion ambitions.

Author contributions: Delphin Kamanda Espoir conceived the key ideas for this research paper. He designed the methodology, collected and analysed the data, and presented and discussed the results. He also worked on the conclusion. Regret Sunge conceived the key ideas for this research paper, worked on the introduction and literature review, and the policy implications of the finding. Frank Bannor conceived the key ideas for this research paper, collected and analyzed the data. He also worked on the literature review, results and policy implications. All the authors have read and approved the final version of this manuscript.

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Appendix

Table 3: List of countries and country identifier

Country name	Country identifier	Country name	Country identifier
Benin	1	Namibia	25
Burkina Faso	2	Seychelles	26
Cabo Verde	3	South Africa	27
Côte d'Ivoire	4	Tanzania	28
Gambia	5	Zambia	29
Ghana	6	Zimbabwe	30
Guinea	7	Egypt	31
Guinea-Bissau	8	Burundi	32
Mali	9	Rwanda	33
Niger	10	Libya	34
Nigeria	11	Chad	35
Senegal	12	Tunisia	36
Sierra Leone	13	Algeria	37
Togo	14	Morocco	38
Angola	15	Mauritania	39
Botswana	16	Uganda	40
Comoros	17	Equatorial Guinea	41
DRC	18	Kenya	42
Eswatini	19	Ethiopia	43
Lesotho	20	Gabon	44
Madagascar	21	Cameroon	45
Malawi	22	Congo republic, of	46
Mauritius	23	CAR	47
Mozambique	24		

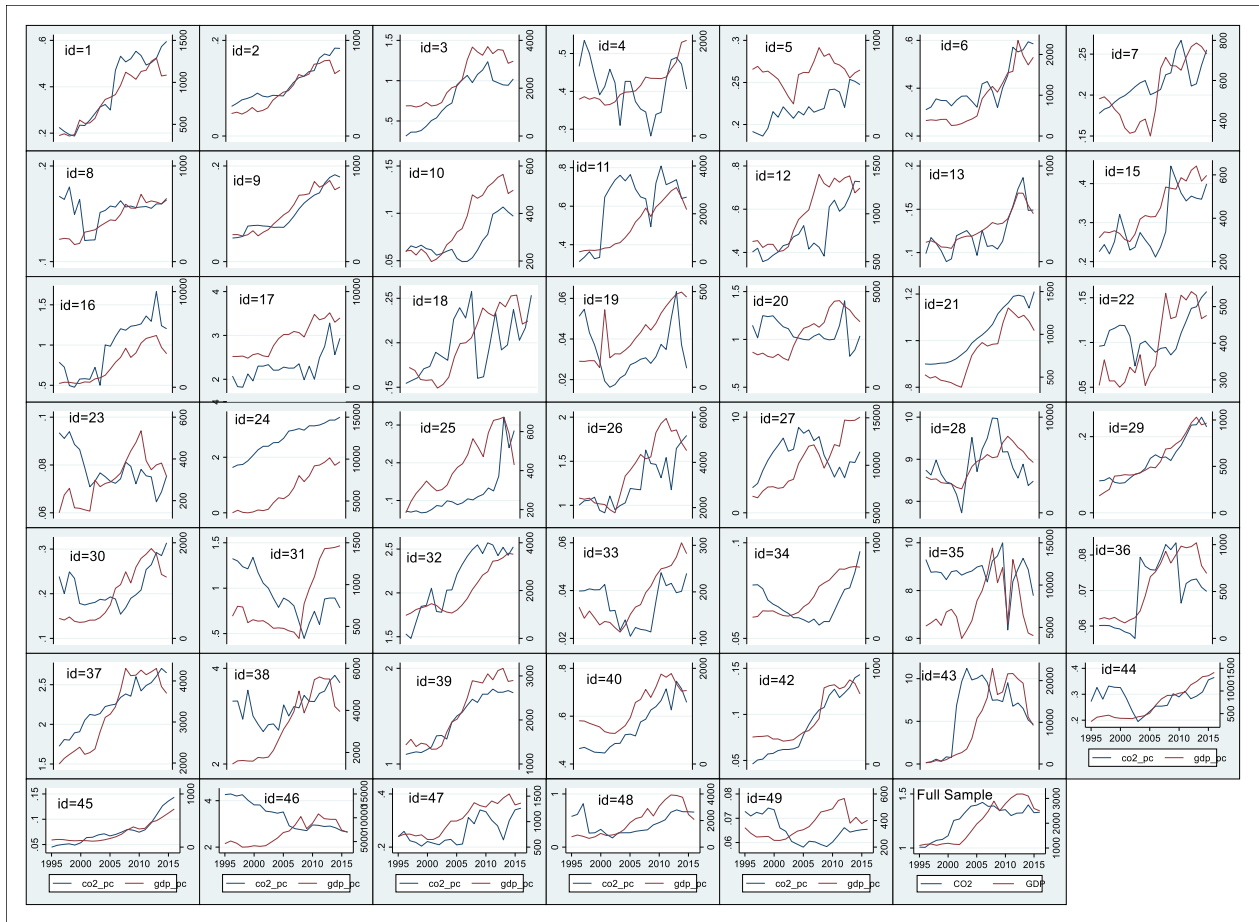


Figure 2: Cross-country trend of GDP and Co2 emissions per capita. Co2 emissions is presented at the left of y axis while GDP at the right of the same axis. Source: Authors' computation using World Bank data.

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