Does foreign direct investment asymmetrically influence carbon emissions in sub-Saharan Africa? Evidence from nonlinear panel ARDL approach

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Research Article

Keywords: asymmetry, carbon emissions, foreign direct investment, environmental quality, pollution, nonlinear ARDL

Posted Date: April 18th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1445534/v1

Does foreign direct investment asymmetrically influence carbon emissions in sub-Saharan Africa? Evidence from nonlinear panel ARDL approach

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Abstract

While several existing panel studies have focused on the linear effect of foreign direct investment on carbon emissions, nonlinear panel studies on this subject remain thin on the ground. This paper examines the asymmetric effect of foreign direct investment on carbon emissions in 41 selected sub-Saharan African countries spanning from 1996 to 2018. In order to decompose foreign direct investment into positive and negative partial sum and examine possible asymmetric effects of the variables on carbon emissions, we used the nonlinear panel ARDL approach. This method accounts for cross-sectional variances that cause inherent heterogeneity in the slope coefficients. Our results show that carbon emissions respond asymmetrically to changes in foreign direct investment. The results further show that in the long run, a positive shock in foreign direct investment increases carbon emissions while a negative shock lowers them. It is recommended that comprehensive investment policies aimed at encouraging aimed clean technology and environmentally-friendly investments be implemented to ensure environmental sustainability.

Keywords: asymmetry; carbon emissions; foreign direct investment; environmental quality; pollution; nonlinear ARDL

Introduction

In recent decades, climate change has become a concern to governments, policymakers and researchers due to its impact on the economy. The main contributor to climate change is carbon emissions accounting for about 70% of total emissions globally ((Lau et al. 2014). In order to reduce these emissions, various governments all over the world have shown commitment by signing the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC framework is a commitment aimed at decreasing the concentration of greenhouse gases (GHGs) in the atmosphere. According to Asongu (2018), although sub-Saharan Africa pollutes the environment less accounting for only 2-3 per cent of the world's carbon dioxide emissions, it is more sensitive to the negative effects of climate change, global warming and worsening environmental quality. These adverse effects of climate change and global warming have prompted the need to identify the potential determinants of carbon emissions so as to proffer solutions.

One of the main determinants of carbon emissions is foreign direct investment. As a result of increased industrialization, free capital movement, and economic globalization, the inflow of foreign direct investment has accelerated over the years (Huang et al. 2022). Foreign direct investment has been identified as crucial driver of economic progress, a conduit for the transfer of advanced and modern technology to host countries, and a potential source of employment (Demena and Bergeijk 2019). It also provides new management skills and infrastructure development. Experts have therefore, recommended developing countries to develop and implement policies that attract foreign direct investment inflow. Some governments, for example, have established special investment zones and Export Processing Zones (EPZs) by offering tax holidays and other investment incentives. Imports of capital goods, equipment, and manufacturing supplies are duty-free under these incentives. Although foreign direct investment makes all these contributions to the economic growth of host countries, it can have detrimental effects on the environment (Zhu et al. 2016). In other words, it raises controversy over the quality of the environment. Thus, the economic gains that may have been achieved as a result of increases in foreign direct investment inflows could be neutralized by increases in carbon emissions. Irsova and Havranet (2013) have noted that the effectiveness of foreign direct investment in mitigating carbon emissions depends largely on the characteristics of the domestic economy. For instance, the technology gap that exists between countries can influence the effect of foreign direct investment on the environment (Irsova and Havranet 2013).

A large number of studies have been documented on the impact of foreign direct investment on carbon emissions. However, what is missing in literature is a panel study on the effect of positive and negative shocks of foreign direct investment on carbon emissions to provide evidence-based policy recommendations. Thus, the objective of this paper is to examine the asymmetric effect of foreign direct investment on carbon emissions in sub-Saharan Africa. The present paper argues that it is not enough to provide policy makers with the direct relationship between foreign direct investment and carbon emissions. Hence, the study goes further than establishing the direct link, to assessing the nonlinear relationship.

This paper provides three-fold contributions to existing literature on environmental pollution. First, while we acknowledge the existing literature on the relationship between foreign direct investment and carbon emissions including asymmetries at the country specific level (Yilanci et al. 2019; Odugbesan and Adebayo 2020; Jakada and Mahmood 2020; Faheem et al. 2022), panel studies on this relationship has not been exhaustive and evidence within the sub-Saharan African context remains sparse. Secondly, although a number of studies attempt to investigate the influence of foreign direct investment on carbon emissions, almost all studies use conventional panel unit root tests (i.e. the Im-Pesaran-Shin (IPS) and the Levin-Lin-Chu (LLC) unit root tests) which fail to take account of cross-sectional dependence and/or heterogeneity across the panel in their estimation processes. It is important to note that ignoring the existence of cross-sectional dependence and heterogeneity across the panel may result in biased estimates and forecasting errors. Thus, this paper seeks to fill this gap by going beyond the conventional unit root tests to include the second generation unit root tests (i.e. the cross-sectional augmented Dickey-Fuller (CADF) and the cross-sectional Im-Pesaran-Shin (CIPS) unit root tests) in our estimation process. By doing so, the reported empirical results become more robust and reliable. Thirdly, in order to account for asymmetric effects in the relationship between foreign direct investment and carbon emissions, we formulate a nonlinear panel autoregressive distributed lag (NARDL) model. This model allows for the consideration of asymmetry in the carbon emissions equation. Also, the approach allows for the computation of the positive and negative partial sum decompositions of the relevant exogenous variable(s) (in this case, foreign direct investment) (Salisu and Isah 2017).

We have chosen the nonlinear panel ARDL framework over other approaches used in modeling asymmetries (for example, quantile regression) because of the following reasons. First, the approach is suitable for capturing inherent heterogeneity effects in the slope coefficients resulting from cross-sectional differences. Secondly, it facilitates the estimation of both the long run and short run responses of carbon emissions to changes.in foreign direct investment.

The choice of sub-Saharan Africa for this study is motivated by (i) the importance of foreign direct investment in the economic development outcomes of the sub-region and (ii) poor environmental management in the sub-region. Jarrett (2017) posits that even though some of the worst energy grid systems in the world can be found in sub-Saharan Africa, there is no political will to address the energy and related environmental issues. An understanding of the nexus between foreign direct investment and carbon emissions will provide governments and policymakers in sub-Saharan Africa a better insight of how positive and negative shocks of foreign direct investment impacts the environmental component of the sustainable development goals (SDG # 13) in the sub-region.

Figures 1 and 2 report the evolution of carbon emissions and foreign direct investment respectively across time for sub-Saharan Africa. Specifically, Figures 1 and 2 show that to some extent, increasing foreign direct investment and carbon emissions have co-movement in the same direction.

The rest of the paper is organized as follows: Section 2 covers both theoretical and empirical literature reviews, while Section 3 covers methods, including data source, empirical model, and estimation approaches. Section 4 deals with the empirical findings and discussions, whereas Section 5 deals with the conclusion and policy recommendations.

2. **Literature review**

The two main theoretical frameworks used to explain the foreign direct investment-carbon emissions nexus are Pollution Haven Hypothesis (PHH) and the Pollution Halo Hypothesis (PH). The PHH argues that some countries have more stringent environmental regulations than others and this makes cost of compliance in the former higher. As a result, companies in pollution-intensive industries would move from countries with stringent environmental regulations to countries where these regulations are relatively weak so that they can emit carbon dioxide and other externalities (Huang et al., 2022). The hypothesis proposes that new investment projects prohibited for environmental reasons in advanced countries seek possibilities in developing countries with laxer environmental rules (Walter and Ugelow 1979) .

On the other hand, the PH proposed by Zarsky (1999) asserts that foreign direct investment can aid the diffusion of cleaner technologies, better environmental management systems and best practices throughout the world, because multinational companies maintain the same environmental standards and procedures across countries. According to this hypothesis, the production structure of companies from the investing developed countries relies largely on green technology and so they contribute to the reduction of carbon emissions in the host countries (Mert and Caglar 2020).

In support of the theoretical assertions, many previous studies have explored the impact of foreign direct investment inflows on carbon emissions to provide evidence or otherwise. For example, using the ARDL approach in a study on Kuwait for the period 1980- 2013, Salahuddin et al. (2018) concluded that increases in economic growth and foreign direct investment stimulates carbon emissions in both the short run and the long run. Also, investigating the PHH in Ghana for the period 1980-2012 and applying the ARDL approach, Solarin et al. (2017) found evidence that foreign direct investment has a positive and significant impact on carbon emissions. Muhammad and Khan (2021) applied the Generalized Methods of Moment (GMM) and the fixed effect model to examine a panel of 170 countries around the world and concluded that foreign direct investment has boosted carbon emissions. Furthermore, in a panel study by Bopkin (2017) across Africa for the period 1990-2013, the empirical results revealed an increase in foreign direct investment inflows significantly increases environmental degradation. Also, in a study on high, middle and low income countries by Shahbaz et al. (2015), the fully modified ordinary least squares approach was applied and the results confirmed the PHH. The authors found evidence that foreign direct investment increases environmental degradation. Furthermore, Zhou et al. (2018) explored the impact of economic growth, population, foreign direct investment and other economic variables on carbon emissions in China using the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. The study concluded that foreign direct investment increases carbon emissions in Chinese cities. Similarly, Ojewumi and Akinlo (2017) used Panel Vector Autoregressive (PVAR) and Panel Vector Error Correction (PVEC) methodologies on a sample of thirty-three sub-Saharan African countries and concluded that the inflow of foreign direct investment had greater long run positive impact on carbon emissions. Also, Gao et al. (2022) investigated the linear and nonlinear impacts of foreign direct investment and terrorism on carbon emissions for ten fragile economies for the period 1973-2019 using the ARDL and NARDL approaches. The authors found that positive changes in foreign direct investment have significant positive impact on carbon emissions.

In contrast, a study by Tang and Tan (2015) used the cointegration and causality techniques in a study on Vietnam and concluded that foreign direct investment reduces carbon emissions. Also Al-Mulali and Tang (2013) has confirmed the PH. The authors investigated the validity of the pollution haven hypothesis in the Gulf Cooperation Council (GCC) countries using non-stationary panel techniques and found that foreign direct investment inflows have a long run negative relationship with carbon emissions. Again, Zhang and Zhou (2016) examined the impact of foreign direct investment on China's carbon emissions at the national and regional levels using provincial panel data from 1995 to 2010. The authors adopted the SIRPAT model and their results indicated that foreign direct investment's impact on carbon emissions decreases from the western region to the eastern and central regions. Furthermore, in a panel study of 112 Chinese cities, Liu et al. (2018) found evidence that foreign direct investment inflows reduce carbon emissions and advocated the utilization of advanced clean technology acquired by means of foreign direct investment. Additionally, Mahadevan and Sun (2020) contends that total inward foreign direct investment into China indicates a pollution reducing effect in the western and eastern regions while that in the central region remains unchanged. Furthermore, examining the impact of foreign direct investment (FDI) and the potential of renewable energy consumption on carbon dioxide emissions in 21 Kyoto countries using an unbalanced panel data, Mert and Bölük (2016) concluded that foreign direct investment brings in clean technology and improves environmental quality. Duodu et al. (2021) applied system GMM to investigate the relationship between foreign direct investment and environmental quality, taking into account policies and institutions for environmental sustainability for 23 Sub-Saharan Africa countries. The results revealed that foreign direct investment improves environmental quality in the long run.

There are other empirical studies that have confirmed both the PHH and PH. For instance, Guoyan et al. (2021) applied the Panel Smooth Transition Regression Model (PSTR) to explore the nonlinear association between foreign direct investment and carbon emissions in the Middle East and North Africa (MENA) countries. The authors concluded that at a low regime, increase in foreign direct investment increases carbon emissions, but as the economy progresses to the high regime, the relationship between the two variables becomes negative and significant. Again, Using the PSTR model with nonlinear and dynamic features to simultaneously investigate the direct and spillover influences at work in foreign direct investment inflows and carbon emissions, Xie et al. (2020) found evidence that foreign direct investment can directly result in an increase in carbon emissions. On the other hand, the results of spillover effect through economic growth suggest that foreign direct investment can reduce carbon emissions. Furthermore, a study by Solarin and Al-Mulali (2018) has revealed that at country level, foreign direct investment and urbanization increase pollution in the developing countries while they mitigate pollution in the developed countries. Also, Ansari et al. (2019) applied the FMOLS approach to investigate the validity of the PHH for a panel of 29 countries in Asia over the period 1994-2014. The long run results confirmed the presence of the PHH only in East Asia. The study results, however, found evidence that foreign direct investment reduces environmental degradation in Southeast Asia, thereby rejecting the validity of the PHH.

Based on this review of related studies, it is evident that the literature has identified foreign direct investment as one of the dominant determinants of carbon emissions. However, most of the panel studies have used the linear specifications of the foreign direct investment variable, which might be inadequate. In order to address this lacuna, the current paper specifies foreign direct investment both in its linear and nonlinear forms. Also, the use of the nonlinear ARDL framework will facilitate the estimation of both the long run and short run effects of foreign direct investment on carbon emissions. Furthermore, the shortage of panel studies on sub-Saharan Africa regarding the asymmetric effect of foreign direct investment on carbon emissions provides grounds for the present study.

Methodology and data source

Theoretical Framework

The environmental Kuznets Curve (EKC) hypothesis assumes a quadratic relationship between economic growth and carbon emissions. Thus, under the EKC framework, the base EKC model can be stated as follows:

$$CO_{2i,t} = \alpha_0 + \alpha_1 EC_{i,t} + \alpha_2 EG_{i,t} + \alpha_3 EG_{i,t}^2 + \lambda_{i,t} \quad (1)$$

Where CO_2 represents carbon emissions, EC is energy consumption and EG^2 is the square of economic growth. Recent studies such as Ahmad et al.(2021), Zhou et al. (2018) and Kaya et al. (2017) argue that foreign direct investment inflows can explain the change in the level of carbon emissions and incorporate it into the base EKC model. Thus, a modified EKC model can be stated as follows:

$$CO_{2i,t} = \alpha_0 + \alpha_1 EC_{i,t} + \alpha_2 EG_{i,t} + \alpha_3 EG_{i,t}^2 + \alpha_4 FDI_{i,t} + \lambda_{i,t} \quad (2)$$

Where FDI represents foreign direct investment. It is instructive to note that foreign direct investment shocks may be expected to have different effects on the carbon emissions of countries. Recent empirical studies have shown that the effects of foreign direct investment could be asymmetric (Gao et al. 2022; Udemba 2021). In other words, positive foreign direct investment shocks do not have an equivalent negative foreign direct investment shocks. Thus, we remove the square of economic growth in equation (2) and partition foreign direct investment into positive and negative foreign direct investment shocks. The revised equation is written as

$$CO_{2_{i,t}} = \alpha_0 + \alpha_1 EC_{i,t} + \alpha_2 EG + \alpha_3 FDI^{+}_{i\ ,t} + \alpha_4 FDI^{-}_{i,t} + \lambda_{i,t} \qquad (3)$$

Where FDI^{+} and FDI^{-} denote positive and negative foreign direct investment shocks respectively.. In the next section, we describe the data used for estimation as well as the empirical model.

Data source

In this study, a balanced annual panel data for 41 sub-Saharan African countries spanning from 1996 to 2018 was used. These countries were selected (see Appendix 1) based on the availability of data, which was obtained from the World Development Indicators (WDI) online database of the World Bank (2021). It is worthwhile to note that all variables (except foreign direct investment as a percentage of Gross Domestic Product (GDP) are transformed into natural logarithms to avoid heteroskedacticity and spurious regression results. Table 1 presents the sources and description of the variables used in this paper.

Empirical model

In estimating our model, the study employs robust panel methods referred to as the Mean Group (MG) estimator and the Pooled Mean Group (PMG) estimator. The MG estimator relies on estimating N time series regressions and averaging coefficients while the PMG estimator has to do with the combination and pooling of coefficients (Blackburne III and Frank 2007). The Hausman test is used in determining whether there is any systematic difference between the MG and the PMG.

The symmetric panel ARDL

We begin by assuming a symmetric response of carbon emissions to changes in foreign direct investment. Thus, the symmetric version of the panel ARDL is given as follows:

$$\Delta \ln CO_{2it} = \beta_0 + \beta_{1i} \ln CO_{2i,t-1} + \beta_{2i} FDI_{i,t-1} + \beta_3 \ln REC_{i,t-1} + \beta_4 \ln RGDPPc_{i,t-1} + \sum_{j-1}^{N1} \lambda_{ij} \Delta \ln CO_{2i,t-1} + \sum_{j-1}^{N2} \gamma_{ij} \Delta FDI_{i,t-1} + \sum_{j-1}^{N3} \varphi_{ij} \Delta \ln REC_{i,t-1} + \sum_{j-1}^{N4} \rho_{ij} \Delta \ln RGDPPc_{i,t-1} + \mu_I + \varepsilon_{it}$$

$$i = 1,2 \ldots\ldots\ldots\ldots\ldots N$$
$$t = 1,2 \ldots\ldots\ldots\ldots\ldots T \qquad (4)$$

As already indicated in Table 1, $\ln CO_{2it}$ is the natural log of carbon emissions (in kilotons) (representing environmental degradation) for each unit i, over a period of time t. FDI represents foreign direct investment as a percentage of GDP, $\ln REC$ and $\ln RGDPPc$ are control variables representing the natural log of renewable energy consumption and the natural log of real GDP per capita (a proxy for economic growth) respectively. Renewable energy is considered as pollution-free, cleaner than fossil energy and useful to reduce carbon emissions (Cheng et al. 2019; Asongu et al. 2019). On the other hand, there is a threshold level of economic growth beyond which further increase is expected to reduce carbon emissions (Odhiambo 2012). μ_i denotes the group specific effect. i represents the sampled units while t is the number of periods. The long run slope (elasticity) coefficient for each cross section is calculated as $-\frac{\beta_{2i}}{\beta_{1i}}$, $-\frac{\beta_{3i}}{\beta_{1i}}$ and $-\frac{\beta_{4i}}{\beta_{1i}}$ since in the long run, the assumption is that $\Delta \ln CO_{2i,t-1} = 0$, $\Delta FDI_{i,t-1} = 0$, $\Delta \ln REC_{i,t-1} = 0$ and $\Delta \ln RGDPPc_{i,t-1} = 0$. On the other hand, the short run estimate for foreign direct investment, renewable energy consumption and real GDP per capita are obtained as γ_{ij}, φ_{ij} and ρ_{ij} respectively. We can include an error correction tern in equation (4) and re-write it as follows:

$$\Delta \ln CO_{2it} = \delta_i \nu_{i,t-1} + \sum_{j-1}^{N1} \lambda_{ij} \Delta \ln CO_{2i,t-1} + \sum_{j-1}^{N2} \gamma_{ij} \Delta FDI_{i,t-1} + \sum_{j-1}^{N3} \varphi_{ij} \Delta \ln REC_{i,t-1} + \sum_{j-1}^{N4} \rho_{ij} \Delta \ln RGDPPc_{i,t-1} + \mu_i + \varepsilon_{it} \qquad (5)$$

Where $\nu_{i,t-1} = \ln CO_{2it-1} - \phi_{0i} - \phi_{1i} FDI_{i,t-1} - \phi_{2i} \ln REC_{i,t-1} - \phi_{3i} \ln RGDPPc_{i,t-1}$ is the linear error correction term for each unit, δ_i represents the error correcting speed of adjustment term for each unit. The long run parameters are computed as $\phi_{1i} = -\frac{\beta_{2i}}{\beta_{1i}}$ and $\phi_{2i} = -\frac{\beta_{3i}}{\beta_{1i}}$ and $\phi_{3i} = -\frac{\beta_{4i}}{\beta_{1i}}$. It can be seen from equations (4) and (5) that there is no decomposition of foreign direct investment into positive and negative shocks. This is due to the assumption of symmetric impact of foreign direct investment shocks on carbon emissions in this scenario.

The asymmetric panel ARDL

Under the asymmetric panel ARDL, the positive and negative shocks of foreign direct investment are not expected to have identical impacts on carbon emissions. Thus, the asymmetric panel ARDL is presented as follows:

$$\begin{aligned} \Delta \ln CO_{2it} &= \beta_0 + \beta_{1i} \ln CO_{2i,t-1} + \beta_{2i}{}^{+} FDI^{+}_{i,t-1} + \beta_{3i}{}^{-} FDI^{-}_{i,t-1} + \beta_{4i} \ln REC_{i,t-1} + \\ &\beta_{5i} \ln RGDPPc_{i,t-1} \sum_{j-1}^{N1} \lambda_{ij} \Delta \ln CO_{2i,t-1} + \sum_{j-1}^{N2} (\gamma_{ij} \Delta^{+} FDI^{+}_{i,t-1} + \gamma_{ij} \Delta^{-} FDI^{-}_{i,t-1}) + \\ &\sum_{j-1}^{N3} \varphi_{ij} \Delta \ln REC_{i,t-1} + \sum_{j-1}^{N4} \rho_{ij} \Delta \ln GDPPc_{i,t-1} + \mu_i + \varepsilon_{it} \end{aligned} \qquad (6)$$

Where FDI^+ and FDI^- represent positive and negative foreign direct investment shocks respectively. The long run coefficients for FDI^+ and FDI^- are computed as $-\frac{\beta_{2i}^{+}}{\beta_{1i}}$ and $-\frac{\beta_{3i}^{-}}{\beta_{1i}}$ respectively. These shocks are respectively calculated as positive and negative partial sum decompositions of changes in foreign direct investment and stated as follows:

$$FDI_t^+ = \sum_{k=1}^{t} \Delta FDI_{ik}^+ = \sum_{k=1}^{t} \max(\Delta FDI_{ik}, 0) \tag{7}$$

$$FDI_t^- = \sum_{k=1}^{t} \Delta FDI_{ik}^- = \sum_{k=1}^{t} \min(\Delta FDI_{ik}, 0) \tag{8}$$

The error correction version of equation (6) is stated as follows:

$$\Delta \ln CO_{2it} = \psi_i \rho_{i,t-1} + \sum_{j-1}^{N1} \lambda_{ij} \Delta \ln CO_{2i,t-1} + \sum_{j-1}^{N2} (\gamma_{ij} \Delta^+ FDI_{i,t-1}^+ + \gamma_{ij} \Delta^- FDI_{i,t-1}^-) + \mu_i + \varepsilon_{it} \tag{9}$$

$\rho_{i,t-1}$ stated in equation (9) expresses the long run equilibrium in the asymmetry panel ARDL while ψ_i computes how long it would take the system to converge to its long run equilibrium when there is a disequilibrium.

Panel unit root tests

In this case, we use panel unit root tests to determine the data series' stationarity. As a result, the Im-Pesaran-Shin (IPS) and Levin-Lin-Chu (LLC) unit root tests were used in this study. These tests are based on the assumption of cross-sectional independence.

Cross-sectional dependence test

It is significant to note that dependence in cross sections can occur due to externalities, disregarded common factors, economic and regional associations (Kasman and Duman 2015)
Thus, disregarding the possible presence of cross-sectional dependence and heterogeneity across the panel can cause biased estimates and forecasting errors. In view of this, we conducted the Pesaran (2004) CD test to verify if there is the presence of cross-sectional dependence. The formula for cross-sectional dependence test is stated as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \hat{\rho}_{ij} \right) \rightarrow N(0,1) \tag{10}$$

Where T is time, N represents the sample size and $\hat{\rho}$ is the coefficient of residuals correlation in individual ordinary least square (OLS) regression.

Where cross-sectional dependence exists in the series, it is recommended that second generation unit root tests such as CADF and CIPS unit root tests are conducted to be sure that the series are indeed, stationary either at I(0) or I(1). Pesaran (2007) proposed the CADF unit root test and it is stated as follows:

$$\Delta y_{i,t} = \alpha_i + \beta_i^* y_{i,t-1} + d_0 \bar{y}_{t-1} + \sum_{j=0}^{p} d_{j+1} \Delta \bar{y}_{t-1} + \sum_{k=1}^{p} c_k \Delta y_{i,t-k} + \mu_{i,t} \quad (11)$$

Where Δy_{t-1} represents the first difference and $\bar{y}_{t-1}$ is the average of all observations in the model at time $t-1$. The CIPS on the other hand, is computed by the average of t statistics of the parameter β_i^* in the CADF model. It is stated as follows:

$$CIPS = \sum_{i=1}^{N} \frac{t_i}{N} \quad (12)$$

Empirical findings and discussion

We performed the IPS and LLC unit root tests in order to ascertain the order of integration of the variables. The integration order of the variables is shown in Table 2. The results show that $\ln CO_2$ has unit root at level but becomes stationary after first difference. However, FDI is stationary even at level.

Furthermore, both $\ln REC$ and $\ln RGDPPC$ are non-stationary at level but become stationary at first difference. The panel cross-sectional unit root test results indicate that the null hypothesis of cross-sectional dependence for carbon emissions, foreign direct investment, renewable energy consumption and economic growth is rejected at 1% level of significance. This implies that the first generation panel unit root framework is not appropriate for this study. The results are shown in Table 3.

Breitung and Pesaran (2008) posit that spatial spillover effects and (un)observable factors between countries and regions are likely to cause a strong panel cross-sectional dependence. Thus, based on the fact that the variables in our model have cross sectional dependence, the CADF and CIPS unit root tests were performed and the results are presented in Table 4.

The CADF and CIPS unit root tests results in Table 4 show that both $\ln CO_2$ and FDI stationary at least, at their first differences. We can therefore, conclude that the variables are stationary at their first difference and not at their second difference.

We proceeded to estimate all the equations using both the MG and PMG estimators and the findings were then subjected to the Hausman test. If the null hypothesis is not rejected, the PMG estimator is more efficient than the MG estimator in the given situation. On the other hand, a rejection of the null hypothesis implies the adoption of the MG estimator. The Hausman test results in Table 5 are in favour of the PMG estimator as the efficient estimator for modeling the effect of foreign direct investment on carbon emissions. Therefore, for both the symmetric and asymmetric models, the PMG estimator was adopted as the efficient estimator. As a result, only the empirical estimates obtained from the PMG estimator are reported and discussed in this paper. The results are discussed under two subheadings: model without asymmetry and with asymmetry of the effect of foreign direct investment on carbon emissions in sub-Saharan Africa.

The computed coefficients suggest that foreign direct investment has a positive influence on carbon emissions in the regression findings of the model without asymmetry (see Table 5A). This finding validates the PHH and also consistent with previous research by Zhou et al. (2015), Shahbaz et al. (2015), Salahuddin et al. (2018), and Muhammad and Khan (2021). The long run estimates reveal that a percentage increase in foreign direct investment induces a 0.006% increase in carbon emissions at 1% level of significance ceteris paribus. In addition, an increase in renewable energy consumption exerts a negative impact on carbon emissions. Holding other factors constant, a percentage increase in renewable energy consumption leads to a reduction in carbon emissions by 1.039% and this is statistically significant at 1%. The result supports the findings by Apergis et al. (2018) which contends that renewable energy consumption contributes to a reduction in carbon emissions in sub-Saharan Africa. However, carbon emissions respond positively to an increase in economic growth all other things being equal. Specifically, a percentage increase in economic growth leads to a statistically significant increase in carbon emissions by 0.284%. This means that the environmental sustainability criterion for Sub-Saharan African countries is yet to be reached.

The short run estimates indicate that all other things being equal, an increase in foreign direct investment by1% leads to a decrease in carbon emissions by 0.004%. However, an increase in renewable energy consumption by 1% will induce a decrease in carbon emissions by 2.593%. This suggests that even in the short run, renewable energy consumption reduces carbon emissions in sub-Saharan Africa. Furthermore, carbon emissions respond positively to increases in economic growth. An increase in economic growth by 1% leads to a positive and statistically significant increase in carbon emissions by 0.224%, ceteris paribus. As expected, the error correction term is negative and statistically significant, as seen in Table 5A.

Having discussed the results for the regression model with symmetry, let us now consider the regression results of the model with asymmetry in Table 5B. According to the long run estimates, a positive shock in foreign direct investment induces a positive and statistically significant effect of 0.006 on carbon emissions, all other things being equal. On the other hand, a negative shock of foreign direct investment induces a negative effect of 0.003 on carbon emissions suggesting that any negative shock of foreign direct investment reduces carbon emissions in the sub-region. The findings demonstrate that a positive foreign direct investment shock has a marginally higher positive impact on carbon emissions as compared to the decreasing impact of a negative foreign direct investment shock. Additionally, the long run results indicate that a percentage increase in renewable energy consumption will lead to a negative and significant impact on carbon emissions by 1.239%. Furthermore, a 0.308% increase in carbon emissions is induced by a 1% increase in economic growth and this is statistically significant at 1%.

The findings further reveal that in the short run, a positive foreign direct investment shock has an insignificant interconnection on carbon emissions. However, a negative shock in foreign direct investment will lead to a statistically significant decrease in carbon emissions by 0.005. Also, an increase in renewable energy consumption by 1% induces a statistically significant decrease in carbon emissions by 2.607% suggesting that any increase in renewable energy consumption in the short run will reduce carbon emissions in sub-Saharan Africa. Additionally, the short run results show that an increase in economic growth leads to an increase in carbon emissions. More specifically, a 1% increase in economic growth increases carbon emissions by 0.208%. Again just like the case of the symmetric model, the error correction term for the model with asymmetry is also negative (-0.390) and statistically significant, which shows a return to equilibrium when there is a disequilibrium. It is worthy to note that the speed of adjustment to steady state for the asymmetric model is slightly higher (by 0.015) than that of the symmetric model.

Conclusion and policy recommendations

This paper provides a perspective on the nonlinear foreign direct investment-carbon emissions relationship in sub-Saharan Africa covering the period from 1996 to 2018. While there have been numerous studies on this link, particularly at the country-specific level, to the best of our knowledge this research appears to be the first to provide some insights into the nonlinearity and heterogeneity in the relationship between foreign direct investment and carbon emissions. In this paper, we formulate a nonlinear panel ARDL model proposed by Shin et al. (2014) so as to account for asymmetries. In panel data analysis, there is the possibility of some variances between cross sections within the same group. We allow for heterogeneity effect in order to ensure that such variations are accounted for in the estimation process. We also estimated the symmetric version of the linear panel ARDL model in order to perform relevant comparative analysis. The results from the symmetric version indicate that in the long run, there is a significant positive relationship between foreign direct investment and carbon emissions. This finding validates the PHH and coincides with studies by Zhou et al. (2015), Shahbaz et al. (2015), Salahuddin et al. (2018), and Muhammad and Khan (2021). The long run estimates further indicate that renewable energy consumption has as decreasing effect on carbon emissions while economic growth increases them.

Furthermore, carbon emissions respond asymmetrically to changes in foreign direct investment in the asymmetric form. The results indicated that in the long run, a positive foreign direct investment shock has a positive impact on carbon emissions, whereas a negative foreign direct investment shock has a negative impact. The positive shock, however, has a marginally higher positive impact on carbon emissions as compared to the decreasing impact of a negative foreign direct investment shock.

This study has drawn the following important policy implications. The confirmation of the PHH in the present study supports prior claims that ineffective and lax regulation, coupled with the inflow of carbon-intensive production through foreign direct investment, have turned sub-Saharan African economies into pollution havens. Unlike, the developed regions, sub-Saharan African countries have a limited option in terms of foreign direct investment selection. However, in the presence of emission convergence like the EKC hypothesis, policymakers could introduce carbon taxing and carbon credits for reducing carbon-intensive technologies and industries across sub-Saharan African countries. Furthermore, sub-Saharan African governments should implement comprehensive investment policies aimed at encouraging clean technology and environmentally-friendly investments so as to ensure environmental sustainability in the sub-region. Future research should consider the asymmetric Granger causality between foreign direct investment and environmental degradation in sub-Saharan Africa for fresh insight.

Acknowledgements

This manuscript has not been submitted to any journal for publication nor is under review at another journal or other publishing venue.

Author contributions

Abdallah Abdul-Mumuni contributed to the study conception, data collection, estimations and analysis. John Kwaku Amoh wrote the introduction section of the manuscript while Barbara Deladem Mensah reviewed related literature on foreign direct investment- carbon emissions nexus. All authors commented on previous versions of the manuscript and all authors read and approved the final manuscript.

Availability of data and Materials

Data sources are outlined above in Table 1 and will be made available on demand.

Declarations

Ethics approval and consent to participate We, the authors, are giving our ethical approval and consent for this paper to be published in ESPR if found publishable.

Consent to participate We, the authors, are giving our consent for participation in this paper to be published in ESPR if found publishable.

Consent for publication We, the authors, are giving our consent for this paper to be published in ESPR if found publishable.

Competing Interests

The author declares no competing interests.

Funding

The authors received no financial support for the research, authorship and/or publication of this manuscript.

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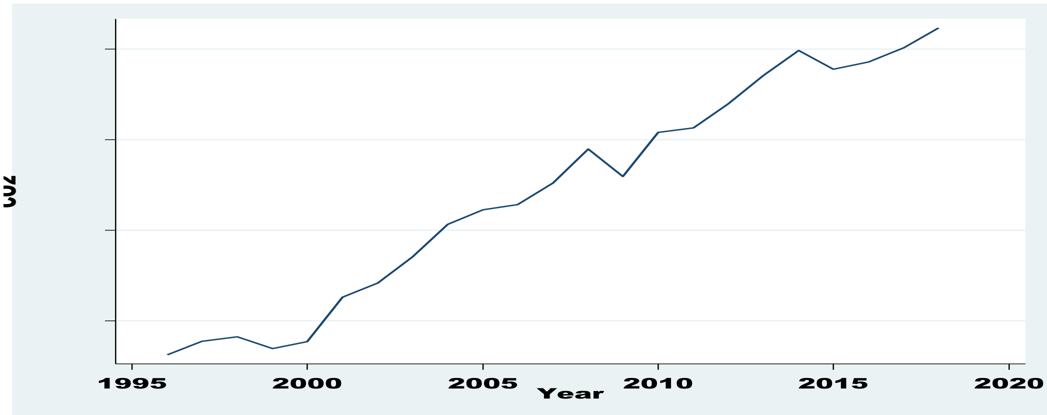
Figures:

Figure 1: Evolution of carbon emissions in 41 sub-Saharan African countries from 1996-2018



Source: World Development Indicators (2021)

Figure 2: Evolution of foreign direct inflows to 41 sub-Saharan African countries from 1996-2018

Source: World Development Indicators (2021)

Table 1: Description of variables

Variable	Definition	Source
$\ln CO_2$	CO_2 emissions (measured in kilotons)	World Development Indicator (2021)
FDI	Foreign direct investment as a percentage of GDP	World Development Indicator (2021)
$\ln REC$	Renewable energy consumption	World Development Indicator (2021)
$\ln RGDPPc$	Real GDP per capita in constant 2010 US dollar used as a proxy of economic growth	World Development Indicator (2021)

Table 2: Panel unit root tests results

Variable	Im-Pesaran-Shin test		Levin-Lin-Chu	
	Level	1st Difference	Level	1st difference
$\ln CO_2$	5.071	-19.156^{***}	-0.641	-18.244^{***}
FDI	-5.051^{***}	-18.092^{***}	-3.392^{***}	-12.747^{***}
$\ln REC$	4.559	-14.235^{***}	1.908	-11.808^{***}
$\ln RGDPPc$	3.740	-10.285^{***}	-1.84^{**}	-14.174^{***}

*** and ** denote 1% and 5% significance levels respectively

Table 3: Empirics for cross-sectional dependence test

	$\ln CO_2$	FDI	lnREC	LnRGDPPc
Pesaran CD	101.969	12.729	53.510	68.526
$p-value$	0.000	0.000	0.000	0.000

Note: *** denote 1% significance level. The CD-test performs the null hypothesis of cross-sectional independence.

Table 4: Empirics for CADF and CIPS unit root tests

	CADF			
	Level		First difference	
Variable	Constant	C & trend	Constant	C & trend
$\ln CO_2$	-2.076^{**}	-2.294	-3.730^{***}	-3.929^{***}
FDI	-2390^{***}	-2.597^{**}	-3.817^{***}	-3.798^{***}
lnREC	-1.890	-2.227	-3.365^{***}	-3.528^{***}
lnRGDDPc	-1.809	-2.151	-2.869^{***}	-3.404^{***}
	CIPS			
$\ln CO_2$	-2.012	-1.543^{**}	-4.095^{***}	-4.143^{***}
FDI	-3.246^{***}	-2.981^{***}	-5.378^{***}	-5.400^{***}
lnREC	-1.950	-1.381	-4.701^{***}	-4.709^{***}
lnRGDPPc	-1.570	-1.148^{**}	-3.822^{***}	-3.392^{***}

Note: *** and** denote 1% and 5% significance level respectively. C represents constant

Table 5: Panel regression results

A. Model without asymmetry (Dependent variable: $\ln CO_2$)			
Variable			
Long run estimates			
Variable	Coefficient	Std. Error	P-value
FDI	0.006***	0.002	0.000
lnREC	-1.039***	0.107	0.000
lnRGDPPc	0.284***	0.093	0.002
Short run estimates			
$ECT(-1)$	-0.314***	0.038	0.000
FDI	-0.004*	0.002	0.083
LnREC	-2.593***	0.594	0.000
lnRGDPPc	0.224**	0.114	0.050
No. of observations	880		
Log likelihood	1424.98		
Hausman test	6.76		
χ_k^2	0.080		
B. Model with asymmetry			
Long run estimates			
FDI^+	0.006***	0.001	0.000
FDI^-	-0.003**	0.001	0.011
lnREC	-1.239***	0.085	0.000
lnRGDPPc	0.308***	0.076	0.000
Short run estimates			
$ECT(-1)$	-0.329***	0.044	0.000
FDI^+	-0.002	0.003	0.639
FDI^-	-0.005*	0.003	0.073
lnREC	-2.607***	0.603	0.000
lnRGDPPc	0.208*	0.121	0.086
No. of observations	880		
Log likelihood	1455.87		
Hausman test	3.86		
χ_k^2	0.425		

Note: ***, ** and * imply significance levels at the 1%, 5%, and 10% levels, respectively.

Appendix 1: List of countries

Benin	Kenya	Sierra Leone	Burundi
Burkina Faso	Madagascar	Seychelles	Central Africa Rep.
Botswana	Mali	Togo	Congo DR
Cote d'Ivoire	Mozambique	Tanzania	Comoros
Cameroon	Mauritius	Uganda	Mauritania
Congo, Republic	Namibia	South Africa	Equatorial Guinea
Cabo Verde	Niger	Malawi	chad
Gabon	Nigeria	Ethiopia	Zambia
Ghana	Rwanda	Lesotho	
Guinea-Bissau	Sudan	Guinea	
The Gambia	Senegal	Angola	