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Research Article

Foreign Direct Investment and CO_2 Emissions in Sub-Saharan Africa: A Heterogeneous Panel Causality Analysis

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Abstract

Following the density of the literature and the consensus in empirical studies, the aim of this article is to examine the nature of the relationship between foreign direct investment (FDI) and carbon dioxide (CO_2) emissions in sub-Saharan Africa (SSA). To this end, the methodological strategy employed is based not only on a theoretically sound multivariate framework, but also on recent developments in panel data econometrics, namely fully modified ordinary least squares (FMOLS) estimators, dynamic ordinary least squares (DOLS) estimators and the vector error correction model. In addition, the stationarity properties of the panel variables are examined, and the panel cointegration technique is used to test cointegrating relationships in the series of variables. The panel is composed of 38 SSA countries over the period 2000-2022. The main results show that in SSA: the variables move together in the long term. A 1% increase in inward FDI increases CO_2 emissions by 0.210%. This result suggests that FDI has flowed to SSA because of its weak environmental regulations, thus verifying the pollution haven hypothesis. In the long term, there is a bidirectional relationship between inward FDI and CO_2 emissions. In all the models used, renewable energy consumption reduces CO_2 emissions. Therefore, SSA needs to put in place effective environmental rules to better guide FDI; put in place strategies to harness and add value to its energy sector, implement policies and strategies that ensure FDI attractiveness without abandoning the environment.

Keywords

Foreign Direct Investment, CO_2 Emissions, FMOLS, DOLS, Sub-Saharan Africa

1. Introduction

The economic and social status of SSA is still precarious and open to internal and external shocks [3]. The developing economies of Africa, and more specifically the countries of SSA, have deployed various practices to ensure the emancipation of their level of sustainable development. Some of these include the promotion of economic growth, industrial-

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ization, real agricultural development, financial development, renewable energy consumption and human capital sustainability [19].

It appears that combining these determinants of growth in the quest for sustainable development has fundamental implications for environmental sustainability. The actual and potential impacts of climate change in SSA are enormous, affecting many aspects of people's daily lives. For example, rising temperatures, drying soils, increased pest and disease pressure, displacement of suitable areas for cultivation, increasing desertification in the Sahara region, flooding, deforestation, and erosion can all be indicators that climate change is beginning and represents one of the greatest environmental, social and economic threats facing SSA.

600,000 people die every year in the African region from causes related to emissions from wood and charcoal burning [8]. The situation is more serious for SSA due to poverty, low technological know-how and most importantly, more than half of the population depends on climate-driven enterprises such as small-scale farming, peasant farming, agriculture and hawking [37]. Consequently, the issue of global warming does not have the same resonance in developing countries, particularly in SSA and developed countries. Unlike in developed countries, in SSA the energy most consumed is that derived from biomass, which accounts for 50% on average of total energy consumption, of which 60-80% is wood fuel [45].

Economic growth has slowed in the region over the past two decades due to wars and other reasons, such as bad weather and declining terms of trade [46]. Despite recent improvements in economic growth, the sub-continent continues to struggle to reduce poverty, with insufficient formal education and/or low quality of education, poor health leading to short life expectancy. It should also be stressed that SSA countries have economies that are highly dependent on natural resources, and SSA is an area that suffers most from natural disasters and global warming, due to its financial difficulties in adapting to them. In this perspective, due to environmental problems, it is estimated that by 2080, between 9% and 20% of arable land in SSA will become much less suitable for agriculture [4].

Although SSA is the least integrated and pollutes the environment the least, it is the most vulnerable to future climate change [2]. Carbon emissions are also heterogeneously distributed across SSA countries. The main contributors are South Africa, Angola and Nigeria, with 853107.128 kt, 34693.487 kt and 120369.275 kt emitted in 2019 respectively. Guinea-Bissau, Comoros and Sao Tome and Principe represent the lowest levels, with 293.36 kt, 201.685 kt and 121.011kt of CO_2 emitted in 2019 [50].

In several SSA countries, the negative implications of recent economic progress outstrip the capacity of local governments to cope with these consequences. Waste collection and sanitation systems cannot handle the volumes of waste generated by economic activities, leading to significant degradation of urban and aquatic environments [3]. Furthermore, theory and evidence suggest that trade openness and FDI promote growth. To take just one example, the remarkable rise of China and the "Four Asian Dragons[1]" is largely due to their integration into the global trading system. Given the many problems associated with an import-substitution[2] industrialization strategy, openness to international trade is now dominant, particularly in developing countries.

Moreover, the ratio of FDI to Gross Domestic Product (GDP) in Africa stands at 5.1%, the highest in the world, confirming the importance of these flows to the continent's economic growth [20]. In fact, FDI was on an upward trend between 1995 and 2001, following the opening up to FDI and international trade spurred by the WTO [38]. FDI flows to SSA rose to USD 32 billion in 2018, an increase of 13% on the previous two years, which were USD 28.5 billion in 2017 and USD 31.8 billion in 2016 [11].

It is important to emphasize that increasing FDI in SSA countries is an integral part of the international agenda for achieving the Sustainable Development Goals (SDGs). In SSA, the contribution of FDI is relatively higher than investment [26]. In addition, the quality of the environment is sensitive to the evolution of FDI [51]. Over the period 2000-2015, SSA has relatively attracted capital from outside [7]. Since the early 1990s, a large and growing literature has studied the role of foreign direct investment in CO_2 emissions. However, empirical contributions have remained contradictory and inconclusive. Consequently, this study stands out by investigating the causal link between these two variables in SSA.

The remainder of this article is structured around four points: section 2 presents a summary review of the literature; section 3 presents the analytical model; section 4 presents the econometric strategies; section 5 presents the results and interpretations; and section 6 concludes with recommendations.

2. Foreign Direct Investment and CO_2 Emissions: A Review of the Literature

Theoretically, two schools of thought diverge, each supporting a hypothesis. The first school of thought supports the "Pollution Haven Hypothesis", according to which weak environmental regulation in a host economy attracts FDI and leads to environmental degradation [10]. This confirms the positive effect of FDI on CO_2 emissions. The second school of thought supports the "pollution halo hypothesis", which states

1 The Newly Industrialized Countries (NICs) in Southeast Asia. They are: South Korea, Hong Kong, Singapore and Taiwan.

2 The aim of this strategy is to protect local businesses from foreign competition [31]. This strategy, which involves replacing imports with local products by setting up trade barriers, develops in two phases. First, consumer goods industries become established, with manufacturing using relatively standardized and readily available techniques. In the second phase, countries have a choice of two options: either they opt for an export orientation, or they embark on a second phase of substitution in intermediate goods, capital goods and consumer durables industries, where capital intensity and scale of production are higher.

that FDI increases energy efficiency and improves environmental quality by reducing carbon emissions through technology transfer and innovative production systems [16].

This theoretical contradiction has prompted empirical investigations. Empirically, however, the subject is still under discussion around the world due to the different results observed. On the one hand, some studies support the "pollution haven hypothesis" (see for example [42, 30, 18, 12, 41, 49, 28]). On the other hand, according to the second approach "pollution halo hypothesis" (see for example [6, 20, 23]). In addition, other studies have highlighted a bidirectional relationship between FDI and CO_2 emissions (e.g. [1, 36]).

Despite the surge in empirical literature on these two hypotheses since the early 2000s, empirical results on the impact of FDI on CO_2 emissions are still inconclusive [5]. Indeed, according to [15], 54% of studies report a negative effect of FDI on CO_2 emissions versus 46% of studies reporting a positive effect.

3. Presentation of the Analysis Model

Our analysis is carried out in a multivariate framework incorporating variables in the model that are assumed to have effects on CO_2 emissions, such as GDP/h, which allows us to test the existence of the Environmental Kuznets Curve (EKC[3]) hypothesis, and renewable energy consumption. Thus, we empirically examine the dynamic relationship between CO_2 emissions, FDI, renewable energy consumption and GDP for a sample of 38 SSA countries[4], as the relevant results in the literature appear controversial and ambiguous.

Following the methodology of [30], the relationship between CO_2 emissions per capita and its determinants (FDI, PIB/h and renewable energy consumption) are described in the following model specification:

$$\ln CO2_t = \alpha_0 + \alpha_1 \ln pib/h_t + \alpha_2 \ln IDE_t + \alpha_3 \ln ER_t + \varepsilon_t. \quad (1)$$

Given that we are using a panel approach, equation (1) becomes:

$$\begin{aligned} \ln CO2_{it} = \alpha_{0i} + \alpha_{1i} \ln pib/h_{it} + \alpha_{2i} \ln IDE_{it} \\ + \alpha_{3i} \ln ER_{it} + \varepsilon_{it}. \end{aligned} \quad (2)$$

All variables are expressed in neperian logarithms. CO_2 is carbon dioxide emissions expressed in metric kilotons per capita ($\ln CO_2$); PIB/h is real gross domestic product per capita (lnPIB/h); FDI is inward foreign direct investment as a percentage of PIB (lnIDE); RE is renewable energy consumption as a percentage of total energy consumption (lnER); is the error term that follows a lognormal distribution.

4. Econometric Strategies

The four strategic points in the econometric analysis are as follows:

4.1. Panel Unit Root Tests

This test is based on the classic Augmented Dickey Fuller (ADF) test for the regression of the following equation:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{it-1} + \gamma_i t + \sum_{j=1}^{k} \theta_{ij} \Delta Y_{it-j} + \varepsilon_{it}. \quad (3)$$

Where Δ is the first difference operator, is the dependent variable, is a white noise disturbance with variance of, and t = 1,..., T.

$\begin{cases} H_0 : \beta_i = 0 \\ H_1 : \beta_i \prec 0 \end{cases}$ Which alternative hypothesis corresponds to stationary.

The test is based on the statistic $t_{\beta_i} = \hat{\beta}_i / \sigma(\hat{\beta}_i)$ (where $\hat{\beta}_i$ is the OLS estimator of β_i in equation (3) and $\sigma(\hat{\beta}_i)$ is its standard error. [33] found that the panel approach substantially increases power in finite samples compared to the ADF test equation, and proposed a panel version based on equation (4) that restricts $\hat{\beta}_i$ by keeping it identical across countries as follows:

$$\Delta Y_{it} = \alpha_i + \beta Y_{it-1} + \gamma_i t + \sum_{j=1}^{k} \theta_{ij} \Delta Y_{it-j} + \varepsilon_{it}. \quad (4)$$

Where i = 1, 2,..., N refers to the countries in the panel. [33] tested

$\begin{cases} H_0 : \beta_1 = \beta_2 = ... = \beta = 0 \\ H_1 : \beta_1 = \beta_2 = ... = \beta \prec 0 \end{cases}$ With the statistic-based test $t_\beta = \hat{\beta} / \sigma(\hat{\beta})$

The IPS test [24] is an extension of the LLC test that relaxes the homogeneity assumption by allowing heterogeneity in the autoregressive coefficients for panel members. This test is based on the mean of the Augmented Dickey-Fuller (ADF) statistics calculated for each individual in the panel. It uses the average of the statistics in equation (3) to perform the following statistic $\overline{Z}$:

3 The Environmental Kuznets Curve (EKC) hypothesis is a theoretical tool describing the relationship between environmental and economic variables. Following the pioneering work of [21], who found evidence of an inverted-U relationship between real income and environmental degradation, empirical evidence since then has provided mixed results

4 Angola, Democratic Republic of Congo, Equatorial Guinea, Ivory Coast, Togo, Eswatini, Mozambique, Botswana, Ghana, Namibia, Uganda, Gabon, Rwanda, Burkina Faso, Guinea, Senegal, Burundi, Guinea-Bissau, Seychelles, Cape Verde, Kenya, Sierra Leone, Cameroon, Madagascar, South Africa, Benin, Nigeria, Niger, Zimbabwe, Lesotho, Malawi, Comoros, Mali, Sudan, Republic of Congo, Tanzania, Mauritius.

$$\bar{Z} = \sqrt{N}\left[\bar{t} - E(\bar{t})\right] / \sqrt{V(\bar{t})}\,. \quad (5)$$

Where, $\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{\beta_i}$, $E(\bar{t})$ and $V(\bar{t})$ are respectively the mean and variance of each statistic, and they are generated by simulations. Unlike the IPS test, which is parametric and asymptotic, [34] and [9] propose a simpler, non-parametric unit root test (the Fisher-ADF and Fisher-PP statistics), based on a combination of the p-values of the individual unit root tests. This test is superior to the IPS test [34]. Its advantage is that its value does not depend on the different lag lengths in the individual ADF regressions. [34] proposed to derive tests that combine p-values from individual unit root tests. If we define as the p-value of any unit root test for the cross-section, then under the null hypothesis of unit root for all cross-sections, we have the following asymptotic result:

$$P_{MV} = -2\sum_{i=1}^{N} Ln(p_i) \rightarrow \chi^2(2N)\,. \quad (6)$$

The null and alternative hypotheses are the same as for [24]. Hadri's test is a Lagrange Multiplier (LM) test where the null hypothesis is that there is no unit root in any of the series in the panel versus the alternative of a unit root in the panel. As with the [32] test, [22] test is based on residuals from individual OLS regressions on a constant, or on a constant and a trend. If we include both the constant and a trend, we derive estimates of:

$$y_{it} = \alpha_i + \lambda_i t + e_{it} \quad (7)$$

Under the null hypothesis of stationarity, the asymptotic result is given by:

$$Z = \frac{\sqrt{N}(LM - \xi)}{C} \rightarrow N(0,1)\,;$$

where $LM = \frac{1}{\hat{\sigma}_e^2}\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T} S_{it}^2$, $S_{it} = \sum_{j=1}^{t}\hat{e}_{ij}$ is the cumulative sum of residuals and $\hat{e}_e^2 = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{e}_{it}^2$ is the estimator of σ_e^2 . Hadri (2000) proposes two cases: $\xi = 1/6$ and $C = 1/45$, if the model includes only the constant; $\xi = 1/15$ et $C = 11/6300$, if the model includes the constant and the trend.[5]

4.2. Panel Cointegration Test

The second stage of our empirical work concerns the study of the long-term relationship between CO_2 emissions and inward FDI, using the panel cointegration techniques developed by [39]. The cointegration relationship is specified by the following equation:

$$\ln CO2_{it} = \alpha_i + \beta_i t + \delta_{1i}\ln pib/h_{it} + \delta_{2i}\ln IDE_{it} + \delta_{3i}\ln ER_{it} + \varepsilon_{it} \quad (8)$$

Where i = 1,..., N denotes the number of individuals in the panel, t = 1,..., T denotes the time dimension, α_i is the individual specific effect, β_i is the deterministic trend and ε_{it} is the estimated residual, which represents deviations from the long-term relationship. The structure of the estimated residuals is as follows:

$$\hat{\varepsilon}_{it} = \hat{\rho}_i \hat{\varepsilon}_{it-1} + \hat{\vartheta}_{it}\,. \quad (9)$$

Pedroni proposes seven cointegration tests, four of which are based on the within dimension (intra) and three on the between dimension (inter). Both categories of tests are based on the null hypothesis of no cointegration: $\rho_i = 1\ \forall i$, where ρ_i denotes the autoregressive term of the residuals estimated under the alternative hypothesis. In our analysis, in addition to applying [39] tests, we also use the cointegration tests proposed by [27, 25] to study the relationship between inward FDI and CO_2 emissions in SSA.

The first is the [27] test, which is based on the two-stage Engle-Granger procedure, and imposes homogeneity on panel members. The null hypothesis of no cointegration is tested using an ADF-type test. [27] proposed the following equation:

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it}\,. \quad (10)$$

Where $Y_{it} = \sum_{t=1}^{T} u_{it}$, $X_{it} = \sum_{t=1}^{T} v_{it}$; $\forall t = 1,\ldots,T$ et i = 1, 2, …, N.

One of the tests proposed by [27] is based on the ADF test. This test is given by:

$$\hat{\varepsilon}_{it} = \psi\hat{\varepsilon}_{it-1} + \sum_{j=1}^{p}\varphi_j \Delta\hat{\varepsilon}_{it-j} + u_{it,p}\,. \quad (11)$$

Where ψ is selected when the $u_{it,p}$ are uncorrelated under the assumption of no cointegration.

Then, the statistic is:

$$ADF = \frac{t_{ADF} + \frac{\sqrt{6N}\hat{\sigma}_u}{2\hat{\sigma}_{0u}}}{\sqrt{\frac{\hat{\sigma}_{0u}^2}{2\hat{\sigma}_u} + \frac{3\hat{\sigma}_u^2}{10\hat{\sigma}_{0u}^2}}} \xrightarrow[underH_0]{} N(0,1)$$

5 Monte Carlos simulations examined by [22] show that results will be more consistent when T and N → ∞.

Where t_{ADF} is the t-statistic of Ψ, and σ_{0u} comes from the covariance matrix $\Omega = \begin{bmatrix} \sigma_{0u}^2 & \sigma_{0uv} \\ \sigma_{0uv} & \sigma_{0u}^2 \end{bmatrix}$ of the bivariate process $(u_{it}, v_{it})'$.

We also use Fisher's test to aggregate the p-values of individual cointegration tests from Johansen's maximum likelihood statistics [34]. The Fisher test is a non-parametric test that does not assume coefficient homogeneity.

4.3. Estimating the Long-term Panel Relationship: FMOLS and DOLS Estimates

The DOLS and FMOLS estimators are obtained from the following equation:

$$CO2_{it} = \alpha_i + \beta_i X_{it} + \sum_{k=-ki}^{ki} \gamma_{ik} \Delta X_{it-k} + u_{it} : \text{i = 1, 2, …, N; t = 1, 2, …, T} \quad (12)$$

Where Y_{it} is the logarithm of CO_2 emissions in metric tons per capita and X_{it} is the logarithm of the independent variable and Y_{it} and X_{it} are cointegrated with the coefficient β_i, which may or may not be homogeneous across *i*. Note that the characteristic equation of the FMOLS and DOLS estimators is an extension of standard regression, in which lags and leads are incorporated into the cointegrating relationship in order to asymptotically reproduce unbiased estimators and avoid the problems associated with estimating nuisance parameters. According to equation (12), $\xi_{it} = (\hat{u}, \Delta X_{it})$ is a stationary vector made up of the estimated residuals from the cointegration regression and differences in FDI attractiveness.

Also, $\Omega_i = \lim_{T \to \infty} E\left[T^{-1} \left(\sum_{t=1}^{T} \xi_{it} \right) \left(\sum_{t=1}^{T} \xi_{it} \right)' \right]$ is the long-term covariance for this vector process, which can be decomposed as follows: $\Omega_i = \Omega_i^o + \Gamma_i + \Gamma_i'$ where Ω_i^o denotes the contemporaneous covariance and Γ_i is a weighted sum of autocovariances. FMOLS estimators are given by:

$$\hat{\beta}_{FMOLS}^* = N^{-1} \sum_{1}^{N} \left[\sum_{t=1}^{T} \left(X_{it} - \overline{X_i} \right)^2 \right]^{-1} \left[\sum_{t=1}^{T} \left(X_{it} - \overline{X_i} \right) CO2_{it}^* - T \hat{\gamma}_i \right]. \quad (13)$$

Where $CO2_{it}^* = \left(CO2_{it} - \overline{CO2_i} \right) - \frac{\hat{\Omega}_{21i}}{\hat{\Omega}_{22i}} \Delta X_{it}$ and $\hat{\gamma}_i = \hat{\Gamma}_{21i} + \hat{\Omega}_{21i}^0 - \frac{\hat{\Omega}_{21i}}{\hat{\Omega}_{22i}} \left(\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^0 \right)$.

The inter-dimensional estimator is $\hat{\beta}_{GMF}^* = N^{-1} \sum_{i=1}^{N} \beta_{CFM,i}^*$ where $\beta_{CFM,i}^*$ is the FMOLS estimator applied to the ith panel member. The t-statistics are calculated as follows:

$$t_{\hat{\beta}_{GMF}^*} = N^{-0,5} \sum_{i=1}^{N} t_{\hat{\beta}_{CFM,i}^*}$$

where $t_{\hat{\beta}_{CFM,i}^*} = \left(\beta_{CFM,i}^* - \beta_0 \right) \left[\Omega_{11i}^{-1} \sum_{t=1}^{T} \left(X_{it} - \overline{X_{it}} \right)^2 \right]^{0,5}$.

$t_{\hat{\beta}_{CFM,i}^*}$ is the test statistic calculated for the ith panel member. Its asymptotic distribution is the normal distribution centered reduced.

From equation (13), the DOLS estimator is given by:

$$\hat{\beta}_{DOLS}^* = N^{-1} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} Z_{it} Z_{it}' \right)^{-1} \left(\sum_{t=1}^{T} Z_{it} Y_{it}^* \right) \quad (14)$$

where Z_{it} is a vector of 2(K+1)1. $Z_{it} = X_{it} - \overline{X}_{it}, \Delta X_{it-K}, \dots, \Delta X_{it+K}$ and $Y_{it}^* = Y_{it} - \overline{Y_i}$. The DOLS inter-dimensional estimator can be constructed as follows $\hat{\beta}_{DOLS}^* = N^{-1} \sum_{i=1}^{N} \beta_{CD,i}^*$ where $\beta_{CD,i}^*$ the DOLS estimator applied to the ith panel member is. The t-statistics are:

$t_{\hat{\beta}_{DOLS}^*} = N^{-0,5} \sum_{i=1}^{N} t_{\hat{\beta}_{CD,i}^*}$ where $t_{\hat{\beta}_{CD,i}^*} = \left(\beta_{CD,i}^* - \beta_0 \right) \left[\hat{\sigma}_i^{-2} \sum_{t=1}^{T} \left(X_{it} - \overline{X_{it}} \right)^2 \right]^{0,5}$ is the long-term variance of the residuals from the DOLS regression is $\sigma_i^2 = \lim_{T \to \infty} E\left[T^{-1} \left(\sum_{t=1}^{T} \mu_{it} \right)^2 \right]$.

One of the disadvantages of using the DOLS test is that the degrees of freedom are lower in lags and leads [35], so we note that the FMOLS test requires fewer hypotheses than the DOLS test and therefore tends to deliver more robust results.

4.4. Granger Panel Causality Tests

To test Granger causality in the long term, we use a two-stage process [14]. The first step is to estimate the long-run model for equation (11) to obtain the estimated residuals, ε_{it} (error correction term; henceforth referred to as ECT). The second step is to estimate the Granger causality model with a dynamic error-correction model. The error-correction model is specified as follows:

$$\Delta \ln CO2_{it} = \alpha_{1i} + \sum_{k=1}^{q} \theta_{11ik} \Delta \ln CO2_{it-k} + \sum_{k=1}^{q} \theta_{12ik} \Delta \ln PIB/h_{it-k} + \sum_{k=1}^{q} \theta_{13ik} \Delta \ln IDE_{it-k}$$

$$+ \sum_{k=1}^{q} \theta_{14ik} \Delta \ln ER_{it-k} + \lambda_{1i} ECT_{it-1} + \mu_{1it}\,; \tag{15}$$

$$\Delta \ln IDE_{it} = \alpha_{2i} + \sum_{k=1}^{q} \theta_{21ik} \Delta IDE_{it-k} + \sum_{k=1}^{q} \theta_{22ik} \Delta \ln PIB/h_{it-k} + \sum_{k=1}^{q} \theta_{23ik} \Delta \ln CO2_{it-k}$$

$$+ \sum_{k=1}^{q} \theta_{24ik} \Delta \ln ER_{it-1} + \lambda_{2i} ECT_{it-1} + \mu_{2it}\,; \tag{16}$$

$$\Delta \ln PIB/h_{it} = \alpha_{3i} + \sum_{k=1}^{q} \theta_{31ik} \Delta \ln PIB/h_{it-k} + \sum_{k=1}^{q} \theta_{32ik} \Delta \ln CO2_{it-k} + \sum_{k=1}^{q} \theta_{33ik} \Delta \ln IDE_{it-k}$$

$$+ \sum_{k=1}^{q} \theta_{34ik} \Delta \ln ER_{it-k} + \lambda_{3i} ECT_{it-1} + \mu_{3it}\,; \tag{17}$$

$$\Delta \ln ER_{it} = \alpha_{4i} + \sum_{k=1}^{q} \theta_{41ik} \Delta \ln ER_{it-k} + \sum_{k=1}^{q} \theta_{42ik} \Delta lnPIB/h_{it-k} + \sum_{k=1}^{q} \theta_{43ik} \Delta CO2_{it-k}$$

$$+ \sum_{k=1}^{q} \theta_{44ik} \Delta \ln IDE_{it-k} + \lambda_{4i} ECT_{it-1} + \mu_{4it} \tag{18}$$

where Δ is the first difference operator; k is the number of delays determined by the Schwarz Information Criterion (SIC); ECT_{it-1} is the one-period lagged error correction term derived from the long-term cointegration relationship. According to [14], this term materializes recall forces and makes it possible to determine the duration of shock absorption. To determine this duration, $\left|\frac{1}{ECT_{it-1}}\right|$ gives the integer part of the number of years of absorption.

We can identify the sources of causality by testing the significance of the coefficients of the lagged dependent variables in equations (15) to (18). The specification of the equation allows us to test both short-term and long-term causality. For example, in the equation for CO_2 emissions (equation (15)), the short-term causality of GDP per capita, inward FDI and renewable energy consumption are tested respectively on the basis of H_A: $\theta_{12ik} = 0$ $\forall i$ and k, H_A: $\theta_{13ik} = 0$ $\forall i$ and k and H_A: $\theta_{14ik} = 0$ $\forall i$ and k.

5. Analysis of Results and Interpretation

In this section, we present the results and interpret the tests before presenting the results of the estimations.

5.1. Results and Interpretation of Unit Root and Panel Cointegration Tests

Before moving on to the interpretation of the cointegration tests, it is worthwhile presenting the unit root tests.

5.1.1. Panel Non-stationarity of the Variables Inward FDI and CO_2 Emissions

It should be noted that the tests for the series used are carried out in level and first difference.

Table 1. *Results of panel unit root tests.*

Variables		LLC	Breitung	IPS	ADF	PP	Hadri	$Hadri_c$
In level	$lnCO_2$	0,652 (0,521)	1,251 (0,854)	2,558* (0,000)	3,594 (0,100)	4,002 (0,336)	4,256 (0,554)	2,245* (0,000)
	LnPIB	0,022 (0,254)	3,701 (0,548)	7,878 (0,772)	-1,282 (0,811)	2,884 (0,996)	4,018 (0,621)	5,021 (0,362)
	lnIDE	2,112 (0,114)	1,111 (0,963)	-0,214 (0,963)	9,245 (0,845)	1,891 (0,145)	5,256* (0,000)	4,114* (0,000)
	LnER	0,215 (0,451)	1,895 (0,571)	0,287 (0,741)	4,253 (0,205)	7,241* (0,000)	8,562* (0,000)	3,587* (0,000)
In first difference	$\Delta lnCO_2$	-4,01* (0,000)	-0,559* (0,000)	-1,11* (0,007)	44,33* (0,007)	81,01* (0,007)	5,012* (0,000)	1,230* (0,000)
	ΔlnPIB	1,14* (0,001)	0,021* (0,000)	-2,77* (0,000)	49,51* (0,001)	52,12* (0,000)	-1,210* (0,000)	1,237* (0,000)
	ΔlnIDE	-0,25* (0,000)	7,21* (0,000)	1,457* (0,000)	10,87* (0,001)	7,96* (0,001)	-1,111 (0,201)	0,827* (0,001)
	ΔlnER	-4,28* (0,000)	-5,777* (0,001)	-3,58* (0,003)	65,62* (0,000)	63,22* (0,000)	4,555* (0,000)	0,989* (0,008)

Note: * Indicates that the statistic is significant at the 1% level. Δ is the first dissimilarity operator. Hadric denotes heteroskedastic coherent Z-stat, ADF and PP denote MW-ADF Fisher Chi-square and MW-PP Fisher Chi-square respectively. The p-values are in brackets.
Source: Author's estimates

For level variables, we find that the variables are non-stationary for the majority of tests. This result of non-stationarity between variables is also found by [36, 48]. Moving on to first-difference tests, we find that all series are stationary at the 1% significance level. For the purposes of this analysis, we assume a model with a constant and no trend for the individual statistics. As can be seen from Table 1, the null hypothesis of unit root can be rejected in several cases. The results suggest that the variables are non-stationary in level in the majority of tests. However, some variables are stationary in level, namely renewable energies with the PP and Hadri tests; CO_2 emissions with the IPS and Hadri tests; and FDI with the Hadri tests. On the other hand, all variables are stationary in first difference.

5.1.2. Panel Cointegration of Inward FDI and CO_2 Emissions Variables

The analysis of these results suggests that the null hypothesis of no cointegration cannot be rejected at the 5% significance level for all tests. Therefore, there may be a long-run relationship between inward FDI, CO_2 emissions, GDP per capita and renewable energy consumption in the case of our panel of countries.

Table 2. *Results of Pedroni's panel cointegration test ([39, 40]).*

Methods	Intra Dimension (panel statistics)			Inter Dimension (individual statistics)		
	Tests	Stat	Prob	Tests	Stat	Prob
[39]	V Panel statistics	0,589*	0,000	Group statistics ρ	1,735	0,987
	ρ Panel statistics	-0,253	0,001	Group statistics pp	-1,589	0,893
	PP Panel statistics	-1,411	0,002	Group statistics	-1,719	0,417
	V Panel statistics ADF	-0,986	0,003	ADF		
[40]	V Panel statistics	1,047	0,413			
	ρ Panel statistics	-0,868	0,087			

Methods	Intra Dimension (panel statistics)			Inter Dimension (individual statistics)		
	Tests	Stat	Prob	Tests	Stat	Prob
	PP Panel statistics v	-0,967	0,059			
	Panel statistics ADF	-0,270	0,234			

Notes: The null hypothesis assumes that the variables are not cointegrated. Under the null hypothesis, all statistics are given as normal. ** indicates that the evaluated parameters are significant at the 5% error level.
Source: Author's estimates

The variables are cointegrated with the [39] test in the Intra dimension. However, the [39] tests in the Inter dimension and [40] in the Intra dimension show that the variables are not cointegrated. Therefore, we apply the panel cointegration test of [27]. Table 3 presents the results obtained from this test. It is clear that the null hypothesis of no cointegration is rejected at the 5% significance level.

Table 3. *[27] panel cointegration test.*

Model	ADF	P-value
$lnCO_2$, lnIDE, lnPIB, lnER	-1,205	0,031**

Notes: ADF is the residual based on the ADF statistic [27]. ** indicates that the evaluated parameters are significant at the 5% error level.
Source: Author's estimates

In the following work, we apply the Johansen cointegration test to test the cointegration between $lnCO_2$, lnIDE, lnPIB and lnER. However, before performing the Johansen panel cointegration tests, the optimal lag number is determined from the Akaike (AIC) and Schwarz (SIC) information criteria. The results obtained from the test are presented in Table 4. The decision rule states that if the test statistic is greater than the critical value at a given significance level (1%, 5% or 10%), the null hypothesis is rejected and vice versa.

Table 4. *Results of the Johansen panel cointegration test.*

Null hypothesis	Alternative hypothesis	Trace Test	Eigenvalue test
r = 0	r > 1	41,01* (0,001)	25,25* (0,001)
r ≤ 1	r > 2	8,12 (0,524)	11,21 (0,241)
r ≤ 2	r > 3	14,13 (0,784)	9,37 (0,793)

Note: * denotes that statistical tests are significant at the 1% level.
Source: Author's estimates

The results are quite conclusive: Fisher's tests (the trace and eigenvalue statistics) favor the presence of cointegration relationships between the study variables. Consequently, there is a cointegration relationship between the four variables of our model. Moreover, we can affirm that the variables (CO_2, FDI, GDP and ER) move together in the long term. The next step in this methodological approach is therefore to estimate this relationship through the FMOLS and DOLS.

5.2. Results of FMOLS and DOLS Estimations and Panel Granger Causality

In this section, we present the FMOLS and DOLS estimations before seeing the results of panel Granger causality between the different variables.

5.2.1. FMOLS and DOLS Estimations and Interpretations

The results obtained show that the estimated coefficients are significant at the 1%, 5% and 10% thresholds (*Table 5*). Furthermore, since the variables are expressed in logarithms, the coefficients can be interpreted in terms of elasticities.

Table 5*. Long-run elasticities from FMOLS and DOLS estimators.*

Dependent variable $lnCO_2$	FMOLS				DOLS			
	Independent variables				Independent variables			
	lnIDE	lnIDE, lnPIB	lnIDE, lnER	lnIDE, lnPIB, lnER	LnIDE	lnIDE, lnPIB	lnIDE, lnER	lnIDE, lnPIB, lnER
Inter results								
C	0,210** (0,031)	0,725** (0,038)	0,001* (0,002)	0,035*** (0,072)	0,238** (0,042)	1,415** (0,024)	0,002* (0,001)	0,058*** (0,071)
With TD	0,471** (0,04)	0,998*** (0,08)	0,999** (0,04)	0,251* (0,007)	0,325*** (0,077)	1,830 (0,214)	0,101** (0,023)	0,011* (0,001)
Intra results								
C	0,111** (0,041)	0,994** (0,049)	0,005* (0,001)	0,071*** (0,06)	0,283** (0,044)	0,871** (0,038)	0,004* (0,004)	0,041*** (0,07)
With TD	0,144*** (0,07)	0.771* (0,001)	0,006*** (0,08)	0,035 (0,874)	0,477*** (0,07)	0,610 (1,444)	0,007** (0,031)	0,071 (0,755)

Note: C and TD indicate dependent variable, constant and deterministic trend respectively.
P-values are in parentheses. T-statistics correspond to H0: βi =1. *, **, *** present the significance of the parameters at the threshold at the thresholds of 1%, 5% and 10% respectively.
Source: Author's estimates

Overall, the results of this study show that there is a relationship between CO_2 emissions and inward FDI in SSA. This result corroborates those of [29]. The impact of inward FDI on CO_2 emissions in SSA is positive and significant at the 5% level. In terms of elasticity, the results of this study indicate that a 1% increase in inward FDI in SSA increases CO_2 emissions by 0.210%. This therefore shows that the increase in inward FDI in SSA contributes to environmental degradation.[6]. This impact remains positive, however, when the gross domestic product variable is taken into account.

With GDP per capita, a 1% increase in inward FDI leads to an increase in CO_2 emissions of 0.725%. This result confirms the "pollution haven" hypothesis in SSA, i.e. FDI is directed to SSA because of their weak environmental regulations. With renewable energy consumption, a 1% increase in inward FDI leads to a small increase in CO_2 emissions of 0.001%. Despite this positive effect, this result shows that the use of renewable energy leads to a decrease in the rate of CO_2 emissions and therefore tends to improve the quality of the environment in SSA. [36] in Turkey, and [2] in SSA countries found the same result. Taking into account GDP per capita and renewable energy consumption, a 1% increase in inward FDI leads to an increase in CO_2 emissions of 0.035%.

5.2.2. Short-run and Long-run Directional Causality and Speed of Adjustment

The results obtained from Granger causality are presented in *Table 6*. Since the variables in the model are cointegrated, the direction of causality can be divided into short-run causality and long-run causality. The optimal lag structure of a period is determined using the Akaike and Schwarz information criteria. In the short run, there is no causality between CO_2 emissions, inward FDI and renewable energy consumption. Furthermore, CO_2 emissions have a negative and statistically significant effect on GDP per capita in SSA. Indeed, a 1% increase in CO_2 emissions would lead to a decrease in real GDP per capita of 0.080%.

6 This result corroborates those found by [49] in emerging countries [44] in the case of high-, middle- and low-income countries; [13] in the case of Turkey; [43] in the case of France.

Table 6. Results of panel Granger Causality tests.

			Dependent variables				Sense of causality
			$\Delta lnCO_{2t}$	$\Delta lnPIB_t$	$\Delta lnIDE_t$	$\Delta lnER_t$	
Source of Causality (Independent variables)	CT	$\Delta lnCO_{2t}$	-	-0,08** (0,032)	0,024 (0,981)	-0,041 (0,781)	CO_2→PIB
		$\Delta lnPIB_t$	0,017* (0,001)	-	0,001** (0,032)	0,017 (0,741)	PIB→CO_2, IDE
		$\Delta lnIDE_t$	0,214* (0,002)	0,141* (0,001)	-	0,003* (0,002)	IDE→CO_2, PIB, ER
		$\Delta lnER_t$	-0,008* (0,001)	0,049* (0,005)	0,013 (0,897)	-	ER→CO_2, PIB
	Test CJ (CT et LT)	$\Delta lnCO_{2t-1}$, ECT_{t-1}	-	4,014* (0,001)	2,014* (0,004)	3,893** (0,041)	CO_2→PIB, IDE et ER
		$\Delta lnPIB_{t-1}$, ECT_{t-1}	4,251* (0,004)	-	2,111* (0,001)	5,625*** (0,052)	PIB→CO_2, IDE et ER
		$\Delta lnIDE_{t-1}$, ECT_{t-1}	3,333* (0,007)	2,111* (0,002)	-	2,241** (0,024)	IDE→CO_2, PIB et ER
		$\Delta lnER_{t-1}$, ECT_{t-1}	2,582* (0,002)	4,257** (0,032)	2,258*** (0,08)	-	ER→CO_2, PIB et IDE

Note: X→Y means that variable X Granger-causes variable Y. CT, LT, and CJ denote short-run, long-run, and joint, respectively. * denotes that the estimated parameters are significant at the 1%, 5%, and 10% level, respectively.
Source: Author's estimates

Given that our variables of interest are CO_2 emissions and inward FDI in this article, therefore, we will not dwell at length on the other two variables (GDP per capita and renewable energy consumption).

Thus, our results highlight the fact that in the short term, CO_2 emissions have no effect on the attractiveness of FDI in SSA, and on the other hand, inward FDI impacts the environment in SSA through the increase in CO_2 emissions. This reflects a unidirectional causality from inward FDI to CO_2 emissions in SSA. This result corroborates that of [29].

Furthermore, the long-run dynamics which is based on the statistical significance of the error correction terms indicates the speed of adjustment to the long-run equilibrium. This speed indicates that inward FDI, CO_2 emissions, GDP per capita and renewable energy consumption respond to deviations from the long-run equilibrium. Therefore, there is a bidirectional causality between inward FDI and CO_2 emissions in SSA in the long run. This result is identical to those found by [36] in Turkey; [1] in the Mediterranean region, and [47] in Vietnam. According to [17], there is a positive long-term relationship between CO_2 emissions and FDI inflows. Following the results obtained from the cointegration tests, which indicated the presence of a long-run relationship between the variables, we adopt the error correction method by long-run adjustment between the variables.

Table 7. Results of the panel causality test (k = 1).

		Dependent variables			
		$\Delta lnCO_{2t}$	$\Delta lnPIB_t$	$\Delta lnIDE_t$	$\Delta lnER_t$
Source of causality (independent variables)	$\Delta lnCO_{2t-1}$	-0,041 (0,414)	0,451 (0,541)	0,631 (0,451)	0,251 (0,123)
	$\Delta lnPIB_{t-1}$	0,101*** (0,07)	-0,521 (0,691)	0,004** (0,03)	0,023* (0,003)

	Dependent variables			
	$\Delta lnCO_{2t}$	$\Delta lnPIB_t$	$\Delta lnIDE_t$	$\Delta lnER_t$
$\Delta lnIDE_{t-1}$	0,204** (0,04)	0,127** (0,03)	-0,125 (0,631)	0,0023 (0,862)
$\Delta lnER_{t-1}$	-0,147* (0,001)	0,025 (0,571)	0,011 (0,177)	-0,638 (0,477)
ECT_{t-1}	-0,318* (0,001)	-0,396* (0,004)	-0,175* (0,001)	-0,155* (0,003)
C	1,0021** (0,042)	1,314** (0,036)	0,993** (0,041)	0,931** (0,032)

Note: ECT denotes the error correction term. *, ** and *** denote that the estimated parameters are significant at the 1%, 5% and 10% levels respectively.
Source: Author's estimates

Thus, the ECT coefficient of -0.175 indicates that if the attractiveness of investments suffers a shock, it will take about five years and eight months for the shock to be absorbed and allow a return to the long-term equilibrium of incoming FDI in SSA. Similarly, the ECT coefficient of -0.396 indicates that if the economic system suffers a shock, it will take about two years and six months for the shock to be absorbed and allow a return to the long-term equilibrium of GDP per capita in SSA. And the ECT coefficient of -0.155 indicates that if the energy sector suffers a shock, it will take about six years and five months for the shock to be absorbed and for renewable energy consumption to return to the long-term equilibrium in SSA. And finally, an ECT of -0.318 indicates that if the environmental sector suffers a shock, it will take about three years and two months for the shock to be absorbed and for the CO_2 emission rate to return to long-term equilibrium.

6. Conclusion and Policy Recommendations

Moreover, this paper set itself the main objective of empirically assessing the nature of the relationship between inward FDI and CO_2 emissions in SSA. To this end, using a methodological approach based on recent econometric techniques, this paper determined the relationship between the different variables of the analysis model. Several tests were used, namely cointegration tests and stationarity tests. It emerged that the variables move together in the long term and that the increase in inward FDI in SSA contributes to environmental degradation.

This result, moreover, confirms the "pollution haven hypothesis" in SSA. By taking into account the control variables (gross domestic product and consumption of renewable energy), this result was nevertheless positive. However, taking into account the consumption of renewable energy reduces the positive effect of FDI on CO_2 emissions in SSA.

Overall, this shows that the use of renewable energies leads to a reduction in CO_2 emissions and consequently to an improvement in environmental quality in SSA. Applying panel causality tests, we find that if there is a shock to investment attractiveness, it will take around five years and eight months for the shock to be absorbed and for inward FDI in SSA to return to long-term equilibrium. On the other hand, if the environmental sector suffers a shock, it will take around three years and two months for the shock to be absorbed and the CO_2 emission rate to return to long-term equilibrium.

In order to reduce CO_2 emissions, SSA must implement policies and strategies that guarantee growth without abandoning the environment; put in place effective environmental rules to guide inward FDI; put in place strategies to exploit and enhance its energy potential.

Abbreviations

ADF	Augmented Dickey-Fuller
CO_2	Carbon Dioxide Emission
DOLS	Dynamic Ordinary Least Squares
ECT	Error Correction Term
EKC	Environmental Kuznets Curve
FDI	Foreign Direct Investment
FMOLS	Fully Modified Ordinary Least Squares
GDP	Gross Domestic Product
WDI	World Development Indicator
SSA	Sub-saharan Africa

Author Contributions

Mohamadou Oumarou: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Writing – original draft

Mohammadou Nourou: Data curation, Methodology, Supervision, Validation, Visualization

Ibrahim: Formal Analysis, Methodology, Supervision, Validation

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Conflicts of Interest

The authors declare no conflicts of interest.

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