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Effect of Foreign Direct Investment on Environmental Sustainability in Sub-Saharan Africa: A Panel EGLS Cross-Section SUR with PCSE Approach

Daniel Wireko and Patricia Lindelwa Makoni *

Department of Finance, Risk Management and Banking, University of South Africa (UNISA), 1 Preller Street, New Muckleneuk, Pretoria 0002, South Africa; 13932535@mylife.unisa.ac.za
* Correspondence: makonpl@unisa.ac.za

Abstract

This paper examines the impact of foreign direct investment (FDI) inflows on environmental sustainability in 47 Sub-Saharan African (SSA) countries from 1990 to 2022. This study applies panel-estimated generalised least squares (EGLS) cross-section and seemingly unrelated regression (SUR) with panel-corrected standard error (PCSE) to estimate the data. The dynamic panel pooled mean group (PMG) of the autoregressive distributed lag (ARDL) strategy was used to test the presence of long-run co-integrating relationships among the variables, whereas the dynamic panel fully modified ordinary least squares (FMOLS) was used for robustness analysis. Empirical findings show that FDI inflows exacerbate environmental devastation regardless of the indicator used for environmental sustainability. This study notes that FDI propels carbon dioxide emissions, while also contributing to the depletion of both natural and forest resources. However, FDI's CO_2 emissions-enhancing impact is restricted to the short-run period, similar to its effect on natural resource depletion. The study recommends that environmental regulating agencies in SSA host countries should strictly enforce environmental laws to ensure FDI investors' compliance. This study further suggests the harmonisation of FDI policies, the integration of operational codes of practice, and the realignment of environmental regulations and laws in all SSA economies to ensure that no one country becomes a favourable destination for FDI investors relative to others.

Keywords: FDI; environmental sustainability; carbon dioxide emissions; natural resource depletion; static and dynamic panel estimators; Sub-Saharan Africa

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1. Introduction

Foreign direct investment (FDI) plays a substantial role in the sustainable development goals of developing countries [1]. This is because, without capital resources, economic growth processes may be adversely affected. The absence of adequate domestic capital results in the need for external sources of capital for developing countries to pursue economic growth programmes. Ref. [2] reiterates the theoretical and empirical arguments that FDI flows complement domestic capital to engender economic growth of recipient countries, affirming the long-standing position that FDI is growth-enhancing. The neoclassical economic school of thought posits that external capital (in this case, FDI) is complementary to local financial resources for achieving the desired level of economic growth [3]. This position is supported by the argument that FDI flows provide several benefits to recipient

countries, including bridging domestic resource and savings gaps, shoring up foreign exchange resources, and providing managerial skills and technical know-how to local experts [4]. It is equally argued that FDI flows contribute to improving the host nation's balance of payments, facilitating capital investments, technology transfers, and generating new employment opportunities, which eventually stimulate economic growth. Empirical evidence on the positive impacts of FDI on economic growth is abundant [1,4].

However, the processes and mechanisms through which FDI flows relate to environmental sustainability while engendering sustainable development and growth have been a subject of ongoing debate from both theoretical and empirical perspectives. Two dominant but conflicting theoretical perspectives exist: the pollution haven hypothesis and the pollution halo hypothesis. Proponents of the pollution haven hypothesis argue that the activities of foreign firms degrade the environment in countries with weak environmental policies and controls [5,6]. On the other hand, supporters of the pollution halo hypothesis [7,8] believe that foreign enterprises employ efficient and cleaner production technologies, and are also efficient in terms of energy resource utilisation. Consequently, environmental sustainability is not compromised. Evidently, there are divergent views regarding the mechanisms through which FDI's impact on environmental sustainability manifests. This study's aim is to empirically examine the impact of FDI on environmental sustainability, in order to test the validity of the pollution haven and halo theories in the context of the SSA region.

On the empirical literature side, a plethora of studies have been conducted on the effect of FDI on environmental sustainability [9–11]. However, these studies have mostly reported mixed and inconsistent findings. While some studies confirm the pollution haven hypothesis, others validate the pollution halo perspective. Therefore, it appears that no definitive conclusion on FDI's impact on environmental sustainability is available in the current literature. Furthermore, only a few studies measure environmental sustainability in terms of forest and natural resource depletion. A large number of prior studies [9] have measured environmental sustainability using CO_2 emissions as a metric. Using CO_2 data only amounts to concluding that the environment is solely defined by atmospheric conditions. This study addresses this gap by measuring sustainable environment using forest resources and natural resource depletions, in conjunction with CO_2 emissions, to account for the FDI's impact on environmental sustainability, and to determine the long-run co-integrating relationships among the considered variables.

The current literature is polarised regarding the environmental impacts of FDI versus domestic investments, and this remains unresolved academic debate [12]. On the later, some studies suggest that domestic investment improves environmental sustainability [13], while others report that domestic investment exacerbates environmental pollution [12]. Meanwhile, other studies found statistically weak association. Overall, it can be inferred from the literature that the impact of domestic investments on environmental sustainability depends on the sectoral direction of the investment projects.

This study focuses on SSA countries and aims to examine the effects of FDI on environmental sustainability. It is important to highlight that, despite the region being natural resource-rich, it remains highly susceptible to climate-induced risks [14]. For instance, as shown in Figure 1, SSA countries lag behind the Middle East and North African (MENA) countries in terms of natural resources (minerals, coal, oil and gas, excluding forest) depletions. However, the level of natural resource depletion in SSA countries exceeds what pertains in the Latin America and the Caribbean, North American, Europe and Central Asian and the East Asian and the Pacific regions.

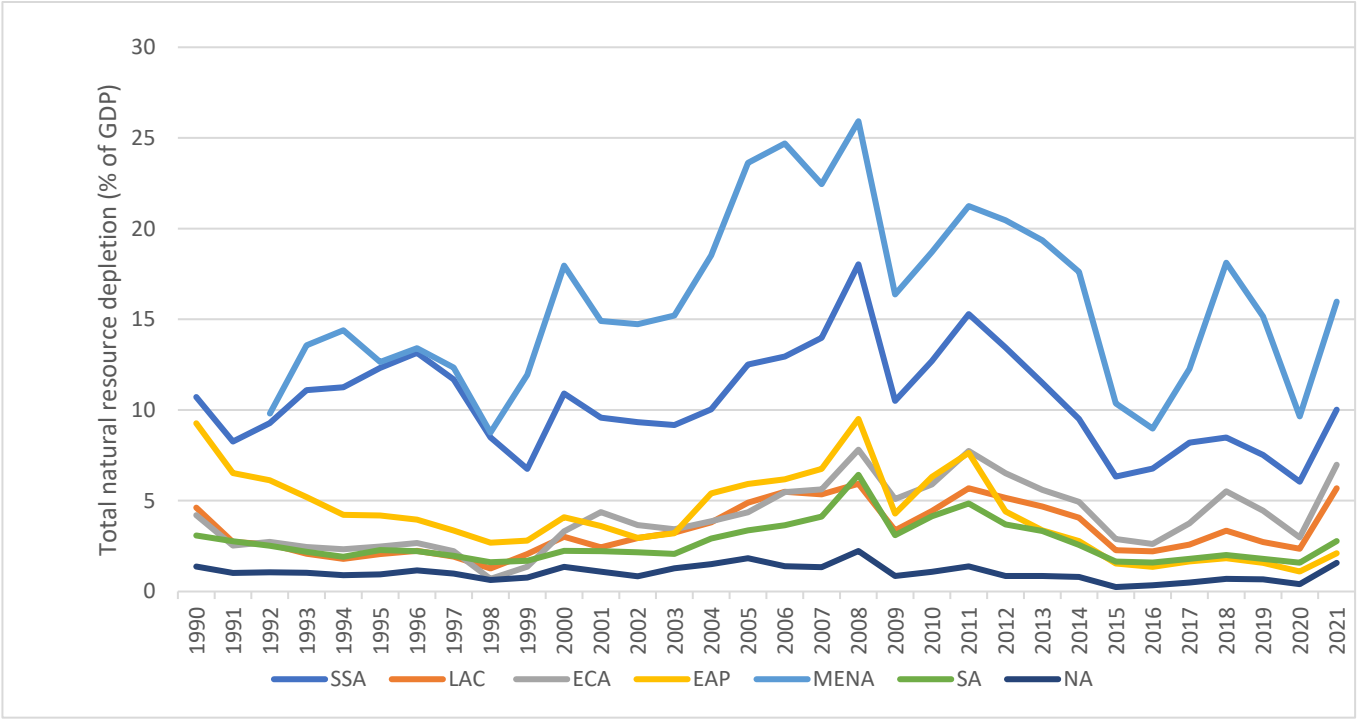


Figure 1. Natural resource depletion as percentage of GDP. *Notes: SSA = Sub-Saharan Africa; LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; EAP = East Asia and the Pacific; MENA = Middle East and North Africa (Including Pakistan and Afghanistan); SA = South Asia and NA = North America*. Source: Authors' work (2025) based on World Bank's World Development Indicators (WDI).

In addition, as shown in Figure 2, the rate of forest resource depletion as a percentage of GDP is very alarming in the SSA region relative to other regions of the world. Ref. [14] found that an influx of FDI to SSA countries initially enhances, but later reduces carbon emission-related environmental problems.

Meanwhile, data from the World Bank shows that when it comes to CO_2 emissions, the SSA region emits the least compared to the other regions. Overall, available data pertaining to environmental sustainability measures at the global level support the fact that the SSA region is most vulnerable to environmental degradation measured by natural and forest resource depletions, despite emitting the least amount of CO_2.

Further, FDI inflows to SSA economies have been declining in recent decades compared to other developing economies. As Figure 3 illustrates, the SSA region has received infinitesimal proportion of global FDI inflows in recent decades (less than 3% of global total from the year 2004 to 2024). Despite the limited FDI inflow to the SSA region, the extent to which natural and forest resources get depleted due to FDI inflows has not been extensively examined empirically, even though some research has investigated FDI's impact on carbon emissions in the region. The overall aim of this study is to investigate the impact of FDI inflows on environmental sustainability in SSA.

This study makes significant contributions to the development of the literature in several ways. First, this study has provided empirical validation of the pollution-haven hypothesis. Second, the study has empirically examined, validated, and demonstrated that STIRPAT theory's predictions are logical in the context of SSA countries. Third, this study tests the validity of the pollution haven and halo theories using natural and forest resource depletions, which have barely been used in empirical studies in recent decades. Methodologically, this study's application of the panel EGLS cross-section SUR with PCSE departs sharply from the first-generation panel estimation approaches employed by some

studies [9,15]. The panel EGLS cross-section SUR with PCSE yields robust and precise parameter coefficients, with improved statistical relevance and reduced standard errors, compared to traditional panel estimation strategies.

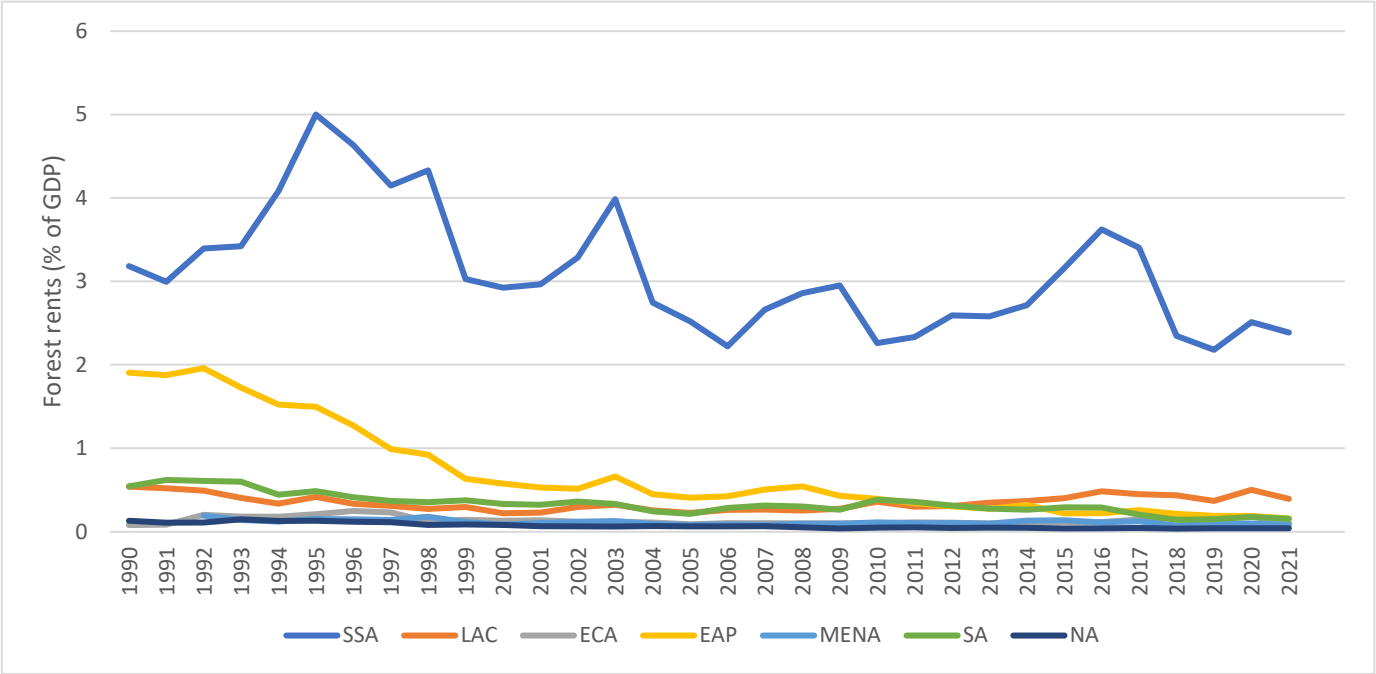


Figure 2. Forest resource depletion as a percentage of GDP. *Notes: SSA = Sub-Saharan Africa; LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; EAP = East Asia and the Pacific; MENA = Middle East and North Africa (Including Pakistan and Afghanistan); SA = South Asia and NA = North America*. Source: Authors' work (2025) based on World Bank's WDI data.

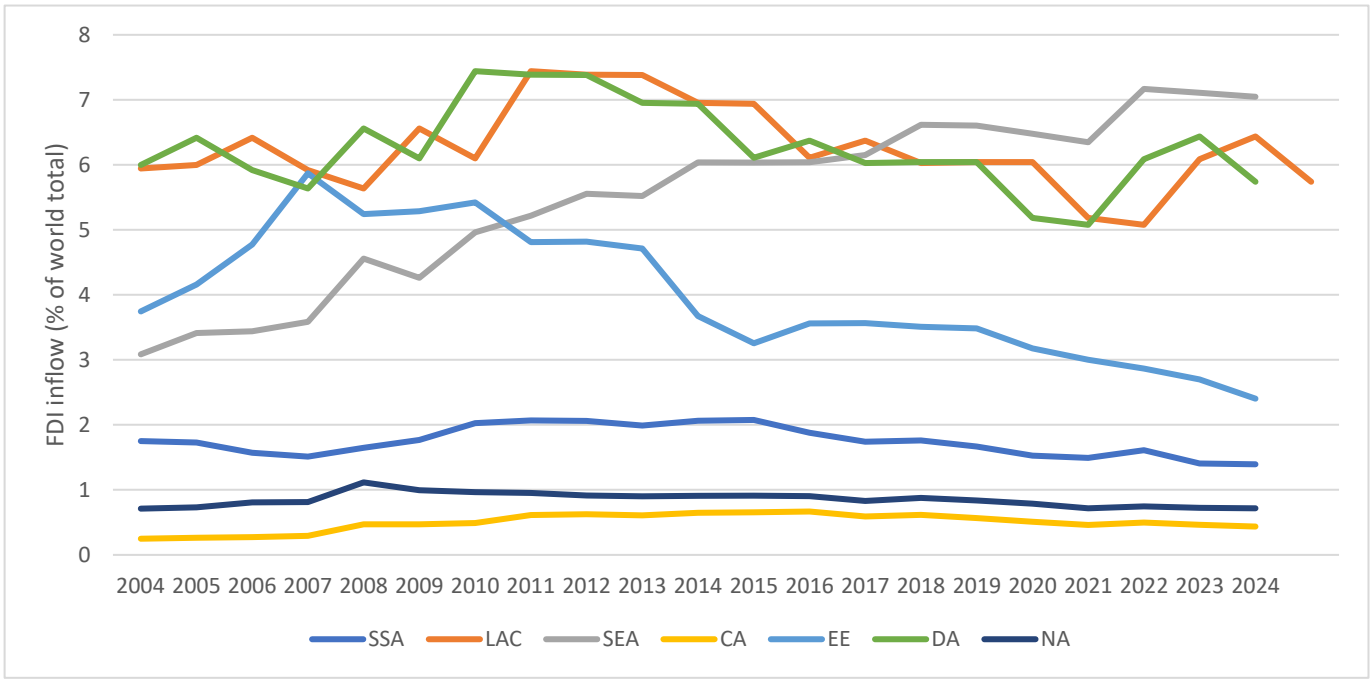


Figure 3. Regional FDI inflows as percentage of global total FDI. *Notes: SSA = Sub-Saharan Africa; LAC = Latin America and the Caribbean; SEA = Southeastern Asia; CA = Central Asia; EE = Eastern Europe; DA = Developing America and NA = North Africa*. Source: Authors' work (2025) based on data from United Nations Conference on Trade and Development UNCTAD).

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature, while Section 3 develops the econometric methodology. The empirical results are presented and discussed in Section 4, Section 5 draws conclusions, presents policy implications and recommendations, outlines limitations, and suggests areas for further study.

2. Literature Review

2.1. Theoretical Literature and Hypothesis Development

Originally developed by [5] and subsequently supported by [16], the pollution haven theory posits that multinational companies (MNCs) prefer to operate in developing countries with less rigid environmental regulatory regimes and lower compliance costs to minimise operational costs and maximise profits. This leads to greater pollution in less developed countries, thereby turning them into safe grounds ('safe havens') for environmental pollution. This theory posits that foreign-based firms degrade environmental quality in developing host countries through FDI. The attraction of foreign firms, and, for that matter, FDIs, to developing countries is based on weak environmental regulations in those countries, which ultimately devastate the quality and sustainability of the environment [6]. The pollution haven theory, therefore, predicts a positive relationship between FDI and degradation or reduced sustainability of the environment. Based on the predictions of the pollution haven theory, our first hypothesis, stated in the null form, is formulated as follows:

H_{01}: *FDI does not significantly increase environmental pollution.*

The somewhat-pollution-halo theory, on the other hand, argues that FDI rather improves environmental quality and therefore contributes significantly to environmental sustainability. The basis of the argument in this theory is that MNCs apply energy-efficient technologies in their operations, as well as engage in cleaner production practices, and are more efficient in the use of energy resources. The underlying condition for the halo hypothesis is that MNCs operate in countries where environmental regulations are stringent, and that the utilisation of efficient technologies coupled with efficient management systems do not subject the environment to degradation. Therefore, our second hypothesis is stated as follows:

H_{02}: *FDI does not significantly reduce environmental pollution.*

2.2. Empirical Literature

Prior scholars have conducted various studies to examine the role of FDI in environmental sustainability [Table 1]. From the studies, it was confirmed that both positive and negative halo effects can occur. For instance, Ref. [17] examined the impact of FDI on environmental sustainability in Africa, as well as the extent to which institutions and governance mechanisms moderate this identified nexus. Using data from 1990 to 2013 for a panel of selected African countries, empirical findings from fixed effects, random effects, and panel-corrected standard errors (PCSE) revealed that FDI strongly engenders environmental pollution, thereby worsening sustainability. Thus, the quantitative results show that FDI has a significantly positive effect on both natural and forest resource depletion, meaning that depletion increases with rising FDI inflows.

Table 1. Summary of FDI-Environment studies.

Author(s) (Year)	Countries (Period)	Estimation Methods	Results/Pollution Theory	Findings
Ref. [17]	African countries (1990–2013)	FE, RE, and PCSE	Positive (Haven effect)	FDI degrades the environment
Ref. [18]	285 Chinese cities (2003–2015)	GMM	Positive (Haven effect)	FDI degrades the environment
Ref. [19]	ASEAN + 5 Countries	Quantile panel	Adverse (Halo effect)	FDI enhances environmental sustainability
Ref. [20]	E-7 economies (2000–2022)	Continuously Updated Fully Modified (CUP-fm) and Continuously Updated Bias-Corrected (CUP-bc)	Positive (Halo effect)	FDI enhances environmental sustainability
Ref. [21]	23 Emerging economies (1996– 2014)	GMM	Positive (Haven effect)	FDI degrades the environment
Ref. [22]	47 SSA countries (1990–2017)	PMG-ARDL	Positive (Haven effect)	FDI degrades the environment
Ref. [23]	44 Countries (2000–2020)	Quantile panel	Positive (Haven effect)	FDI degrades the environment
Ref. [24]	23 SSA countries	GMM	Adverse (Halo effect)	FDI enhances environmental sustainability
Ref. [25]	ASEAN + 3 Countries (1995–2019)	Panel ARDL	Positive (Haven effect)	FDI degrades the environment
Ref. [26]	30 SSA countries (2000–2022)	CCMG and AMG	Positive (Haven effect)	FDI degrades the environment
Ref. [27]	African countries (1990–2019)	PMG-ARDL	Insignificant Positive	FDI has no effect
Ref. [28]	47 SSA countries (1996–2021)	System GMM	Positive (Haven effect)	FDI degrades the environment
Ref. [29]	39 SSA countries (2000–2020)	GMM	Positive (Haven effect)	FDI degrades the environment

Source: Authors' compilation from empirical studies, 2026.

Ref. [18] examined the impact of FDI on carbon emissions in 285 Chinese cities over the period 2003 to 2015. The study employed dynamic panel data regression procedures, utilising the differential GMM and system GMM estimators. Findings indicate that FDI contributes to rising carbon emissions in urban China, primarily due to the indirect carbon footprint associated with the trade. Additionally, a one-year lag in FDI can significantly reduce carbon emissions. Their study did not observe the inverted U-shaped model of the EKC theory, but instead witnessed an inverted N-shaped model for China. Ref. [19] assessed the effect of FDI on carbon emissions in the ASEAN-5 countries. The study draws data from 1981 and 2011. It applies quantile panel regression, reporting that FDI has a negative impact on carbon emissions in countries with medium to high emission rates, thereby confirming the halo effect hypothesis. However, in their study on the moderating influence of FDI on environmental sustainability in the E-7 economies of Brazil, China, India, Indonesia, Mexico, Russia, and Türkiye from 2000 to 2022, ref. [20] found that FDI has emerged as a critical mitigating factor, exhibiting a negative correlation with carbon emissions and moderating the emission-enhancing effects of urbanisation and human capital. Their results emphasised the dual role of FDI as both an economic growth driver, as well as a catalyst for environmental sustainability.

Ref. [21] investigated the combined effect of FDI, quality governance, and technological innovation on carbon emission mitigation among 23 emerging market economies. The study drew data from 1996 to 2014 and applied the system-GMM approach to panel data modelling. Outcomes indicate that FDI contributes significantly to carbon emissions, whereas improved governance structures and technological progress have a detrimental effect on carbon emission levels. Furthermore, the study reports that carbon emissions decrease with the interaction of both political and institutional governance and FDI. Technological innovations, combined with FDI, also minimise the incidence of carbon emissions. Ref. [22] explored how greenhouse gas emissions are determined by economic growth, renewable energy usage, FDI, and governance in 47 SSA countries from 1990 to 2017. The study disintegrated the effects into scale, composition, and technique effects. Applying panel co-integration techniques and quantile panel regression, the study found that marginal increases in renewable energy significantly reduce GHG emissions. In contrast, a combination of governance, economic growth, and renewable energy usage worsens emissions. The interaction of scale, composition, and technique exacerbates climate change. The impacts of individual variables indicate that FDI, economic progress, and governance structures have a positive influence on emissions, whereas renewable energy usage mitigates the negative effects of emissions. Ref. [22] emphasised that the effectiveness of renewable energy utilisation is contingent upon its proportion in the energy mix, technological innovation, and policy focus of individual countries.

Similar findings from other studies in Africa suggest that FDI operations aggravate environmental quality. For instance, ref. [23] focused on South Africa and applied the ARDL technique and Granger causality testing, finding that FDI exacerbates emissions. Ref. [24] examined the nexus between FDI, environmental policies, and institutions and environmental sustainability in 23 SSA countries from 2005 to 2019. Empirical outcomes based on the system GMM procedure indicate that FDI enhances ecological sustainability through its carbon emissions-reducing effect and forest resources-conserving effect. This means that FDI contributes towards reductions in carbon emissions and, at the same time, helps reduce the depletion of forest resources. However, ref. [24] demonstrated that FDI contributes to environmental damage through increased natural resource depletion, whereas robust environmental policies and institutions that promote sustainability and local investment can help mitigate this impact.

Ref. [25] investigated how environmental pollution affects the inflow of FDI among the ASEAN + 3 economies, using annual data from 1995 to 2019. The findings obtained from the panel ARDL show that FDI inflows are strongly determined by environmental degradation, the incidence of corruption, and infrastructure development in the long run. At the same time, inflationary pressures stiffen FDI in the short term.

In a related study, ref. [26] investigated the mediating and moderating roles of industrial development and trade openness in the relationship between FDI and CO_2 emissions across 30 SSA countries from 2000 to 2022. Empirical results from CCMG and AMG estimations show that inbound FDI positively drives pollutant emissions, whereas outbound FDI reduces emissions. In terms of the mediating and moderating impacts, it emerges that industrialisation positively mediates the nexus between FDI and carbon emissions, just as trade opening positively moderates the nexus. These findings suggest that industrial development and trade openness contribute to mitigating or reducing the negative impacts of FDI on emissions.

On the other hand, a few studies found no substantive impact of FDI on emissions and thus argued that different recipient countries' internal variables may account for emissions. For instance, ref. [27] found that FDI does not statistically explain carbon emissions, adding that economic, social, and political factors, as well as host nations' peculiarities and environmental regulations, explain whether inbound FDI activities contribute to rising emissions. Likewise, ref. [28] confirmed the absence of a statistically significant relationship between FDI and emissions, suggesting that a host country's contextual factors, such as its energy mix and environmental standards, may potentially influence FDI's role in environmental emissions. Focusing on SSA countries, ref. [29] investigated the nexus between FDI and environmental emissions among 39 SSA developing economies from 2000 to 2020. The dynamic panel estimation strategies reveal that FDI initially increases emissions but subsequently reduces them, suggesting that the relationship between FDI and emissions does not follow a linear path, but rather an inverse U-shaped pattern. Furthermore, ref. [29] reported that the use of green energy contributes to reducing emissions in the long run, whereas the development of the financial sector exacerbates emission volumes. Ultimately, quality regulations facilitate efforts to mitigate environmental pollution.

3. Methodology and Data

3.1. Sources of Data

This study used secondary quantitative data extracted from the World Bank's WDI database. Three variable groupings were extracted for this study: foreign direct investment (FDI) as the independent variable, and environmental sustainability as the dependent variable, measured by three indicators: CO_2 emissions, natural resource depletion (NRD), and forest resource depletion (FRD). The last group of variables includes controls, which comprise economic growth (EG), trade openness (TO), urban population growth (UPG), renewable energy consumption (REC), and the global financial crisis. The choice of CO_2, as a dependent variable, was informed by the pollution haven and pollution halo hypotheses, whilst the inclusion of NRD and FRD was based on empirical literature [24,29]. The control variables were selected based on the STIRPAT theoretical model which explains the possible determinants of environmental sustainability, and which has been adopted by prior studies [24].

This study did not test the validity of the EKC hypothesis, and for that matter, income levels of the considered countries were excluded from the analysis. Instead, this study focused on pollution consequences of FDI, drawing on the STIRPAT theoretical model and the FDI pollution theories of haven and halo effects. Hence, we used the economic growth rate (EG) as opposed to the absolute income level and its squared term.

The data covered the period from 1990 to 2022 for 47 SSA countries. The inclusion criteria in the panel were determined by data availability and sub-regional representation. SSA countries were considered as opposed to other countries because SSA countries experienced reduced FDI inflows as a percentage of global total FDI inflows relative to other regions of the world. Also, natural and forest resources in SSA have been depleting rapidly over the period under consideration relative to other developing countries of the world, while SSA remains the lowest emitter of CO_2 globally. The period of the study, 1990–2022, coincides with these issues, a feature that makes it so relevant to this study.

The descriptions, measurements, and expectations of the variables are summarised in Table 2.

Table 2. Summary of variables of the Study.

Variable	Measurement Proxy	Description	Expected Sign	Source
Dependent variable: Environmental sustainability	CO_2 emissions	Annual CO_2 emissions (metric tons) as a percentage of GDP	N/A	WDI
	Natural resource depletion (NRD)	Total natural resources rents (excluding forest rents) from oil, natural gas, coal, and minerals (% of GDP)	N/A	WDI
	Forest resource depletion (FRD)	Total annual forest rents as % of GDP, determined as the quantity of roundwood harvest multiplied by the product of regional prices and rental rates.	N/A	WDI
Independent variable: FDI	FDI	Net FDI inflow (% of GDP) is defined as foreigners' acquisition of permanent management interest in a business entity outside the investors' home country.	+	WDI
Control variables: Urban population growth	UPG	Annual percentage of people living in urban areas relative to the total population	+	WDI
Economic growth	GDPGR	Annual growth rate of GDP	+	WDI
Trade openness	TO	Sum of annual export and import of goods and services (% of GDP)	+	WDI
Renewable energy consumption	REC	Renewable energy consumption (% of overall energy consumption)	−	WDI
Global financial crisis	GFC	A binary dummy variable with 1 for the post-GFC years and 0 for the pre-GFC years	+/−	Authors

Source: Authors' compilation from WDI, 2025.

3.2. Theoretical Model

Empirical analysis of the drivers of environmental sustainability is theoretically grounded in the stochastic impact by regression on population, affluence, and technology [STIRPAT] model, developed by [30]. Therefore, the development of empirical models for this study was based on the STIRPAT framework, whose generic structure is

$$ES_{it} = \delta P_{it}^{\alpha} A_{it}^{\beta} T_{it}^{\gamma} \mu^{it} \quad (1)$$

The symbolic identities are ES_{it} = environmental sustainability; P = population; A = affluence; and T = technology. The elasticities of population, affluence, and technology are denoted by α, β and γ, respectively. The error identity is represented by μ^{it},

and it denotes other variables that can influence environmental sustainability, but were not included in the model.

Linearising the theoretical model yields

$$LnES_{it} = \delta + \alpha LnP_{it} + \beta LnA_{it} + \gamma LnT_{it} + \varepsilon_{it} \quad (2)$$

Ref. [24] measured population in terms of urbanisation and affluence in relation to economic growth, while technological innovation was considered a spillover from FDI flows and trade openness. Model 2 is therefore modified as

$$LnES_{it} = \delta + \alpha LnUPG_{it} + \beta LnEG_{it} + \varphi LnFDI_{it} + \gamma LnTO_{it} + \varepsilon_{it} \quad (3)$$

3.3. The STIRPAT Model

The baseline static empirical model obtained from the STIRPAT theoretical framework, incorporating added control variables for examining the effect of FDI on environmental sustainability, is

$$LnES_{it} = \delta + \alpha LnUPG_{it} + \beta LnEG_{it} + \tau LnFDI_{it} + \gamma LnTO_{it} + \gamma LnREC_{it} + GFC_{it} + u_{it} \quad (4)$$

The corresponding baseline functional notation version of model (4) is finally derived as follows:

$$\text{ES} = \text{f (FDI, UPG, EG, TO, REC, GFC)} \quad (5)$$

The definition of acronyms is provided in Table 1.

3.4. Panel Autoregressive Distributed Lag (ARDL) Model

The second part of this study seeks to analyse the dynamic long-run, co-integrating relationships among the variables under study. To address this objective, this study implemented the PSS panel variant of the ARDL bounds testing and modelling technique. The generic form of the unrestricted panel ARDL system of equations is given as

$$\Delta Y_{it} = \alpha_0 + \sum_{k=1}^{p} \varphi_{it} Y_{it-1} + \sum_{i=0}^{q} \delta_{2t} X_{it-1} + \mu_{it} + \varepsilon_{it} \quad (6)$$

From Equation (6), Y_{it} stands for the dependent variable, ES, and X_{it-1} represents the independent variable (FDI); p and q denote the lag length. Substituting the specific variables of this study into Equation (6) yields the re-configured model specifications for our study.

$$\Delta ES_{it} = \varphi_i (ES_{i,\,t-1} - \gamma_{2i} FDI_{it}) + \sum_{j=1}^{p-1} \delta_{ij} \Delta ES_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta FDI_{i,\,t-j} + \mu_i + \varepsilon_{it} \quad (7)$$

As previously defined, ES and FDI represent environmental sustainability and foreign direct investment, respectively. The long-run coefficients of the independent variables are denoted by γ, while those of the short-run are symbolised as delta and beta. The rate at which the system of equations adjusts to the long-run equilibrium state is shown by the script phi. EViews automatically choose the lag length (p and q) of the variables. The long-term co-integrating linkages among the variables are ascertained through the lagged versions of the variables, while the short-run relationships are determined through the differenced variables. The PMG estimation method is used in the study due to its superior efficiency qualities [31].

3.5. Panel Co-Integration Testing

We conducted a panel co-integration test using the McCoskey and Kao procedure to ascertain the existence of long-run equilibrium properties among the variables, given its

relative advantages of being able to detect co-integration among panel datasets involving large regressors, spurious regression estimates, and being a residual-based test [32].

4. Empirical Results and Discussion of Findings

4.1. Descriptive Statistics and Correlation Analysis

The descriptive statistics show that the annual CO_2 emissions range from a minimum of 0.021 metric tons to a maximum of 8.446 metric tons as a proportion of GDP, with a mean value of 0.886. CO_2 has a relatively high standard deviation (SD) value of 1.521. The descriptive statistical properties of natural resource depletion (NRD) indicate that there was a massive depletion of natural resources over the period. The lowest level of depletion stood at only 0.000% of GDP. The mean value of NRD stood at 10.671%, with a SD of 10.406%.

Similarly, it can be observed that forest resource depletion (FRD) was equally devastating, given that an average of 5.497% of GDP was depleted through various anthropogenic activities over the period. These statistics suggest that SSA countries required approximately 5.5% of GDP to restore depleted forest resources or mitigate deforestation through reforestation programmes over the period. The raw data descriptive statistical estimates reveal that net FDI inflows observed for the period under consideration averaged 3.086% of GDP, with a peak value of 56.288% and a minimum value of −17.292% of GDP. This means that FDI inflows into the SSA countries were insignificant for the years under investigation. The negative FDI value indicates that external investment outflows exceeded the inflows, representing a situation of reverse investment from the host countries [4].

Table 3 further reveals the descriptive statistical features of the control variables. First, UPG's average value was 3.762% of the total population, with a maximum value of 31.143% and a minimum value of −2.154%. The SD for UPG stood at 1.849. These statistics suggest that, on average, approximately 4% of the total population in the selected SSA countries resides in urban areas, while in extreme cases, as high as 31% of the population lives in urban areas. The negative value appears to indicate that the proportion of persons living in urban areas compared to the total population decreased at some point during the period. Second, the annual growth rate of gross domestic product (GDPGR) saw a mean rate of 3.675%, with the best growth economies recording values as high as 35.240% in the course of the three-decade period (1990–2022). The minimum value of GDPGR stood at −50.248%, indicating that some of the selected SSA countries experienced a decline in economic activity, or a contraction in economic output, over the period under observation. The corresponding SD was observed at 5.445%.

Third, the openness of the economy to trade (TO) as a share of GDP for the selected SSA countries appeared substantial. This is because TO values range from a minimum of 4.127% to a maximum of 320.939%, with an observed mean value of 67.408%. This means that the volume of trade (the sum of imports and exports) may have contributed substantially to the size of GDP in the SSA countries under review. TO's SD, which stood at 37.230% is a little over half of the mean value, signifying that approximately 55% of TO values deviates from the mean score. Lastly, the mean score of REC (defined as the percentage of total final energy consumption) was 66.564%, while it peaks at 98.300% and then flattens at 0.700%. The associated SD for REC is 26.346%. These figures appear to suggest that over 66% of total energy consumption in the considered SSA countries originates from renewable sources (hydropower, solar, wind, geothermal, and bioenergy). Results pertaining to the VIF generally show the absence of multicollinearity among the independent variables. This is evidenced by the fact that none of the independent variables has a VIF value exceeding 10.

Table 3. Descriptive statistics and correlation estimates of raw data.

Variable /Statistic	Mean	Std. Dev.	Max.	Min.	Obs.	VIF	1	2	3	4	5	6	7	8
1. CO_2	0.886	1.521	8.446	0.021	1237	-	1.000							
2. NRD	10.671	10.406	59.683	0.000	1237	-	−0.284 *	1.000						
3. FRD	5.497	5.426	34.122	0.000	1237	-	−0.672 *	0.539 *	1.000					
4. FDI	3.086	5.057	56.288	−17.292	1237	1.382	0.160	0.044	−0.086 *	1.000				
5. UPG	3.762	1.841	31.143	−2.154	1237	1.125	−0.364 *	0.317 *	0.321 *	−0.019	1.000			
6. GDPGR	3.675	5.445	35.224	−50.248	1237	1.026	−0.103 *	0.049 *	0.052 *	0.200 *	0.163 *	1.000		
7. TO	67.408	37.230	320.939	4.127	1237	1.161	0.596 *	0.026	−0.346 *	0.371 *	−0.194 *	0.034	1.000	
8. REC	66.564	26.346	98.300	0.700	1237	1.416	−0.414 *	0.417 *	0.083 *	−0.177 *	0.335 *	0.084 *	−0.537 *	1.000

Source: Authors' computations from EViews 12, 2025. Notes: * for $p < 0.1$. Notes: CO_2 = CO_2 emissions (metric tons); NRD = Natural resource depletion measured as total natural resource rents (% of GDP); FRD = Forest resource depletion (% of GDP); FDI = Net FDI inflow (% of GDP); UPG = Urban population growth (% of total population); GDPGR = Gross domestic product growth rate (Annual %); TO = Trade openness (% of GDP); REC = Renewable energy consumption (% of overall final energy consumption).

The results of the correlation coefficient estimates generally affirm the absence of multicollinearity in the dataset. The evidence is that none of the variable pairings has a correlation coefficient of 0.6. The highest coefficient occurs between TO and CO_2 emissions (r = 0.596, $p < 0.01$). Among the independent variables, the correlation coefficients have been low, just as among the independent and control variables. These results confirm the results obtained from the VIF, which revealed that multicollinearity is absent. Table 3 indicates a statistically insignificant but proportional association between FDI and CO_2 emissions (r = 0.160, $p > 0.1$). Similarly, the association between FDI and NRD is positive but insignificant (r = 0.044, $p > 0.1$). On the other hand, FDI and FRD are negatively associated at 1% significance level (r = −0.086, $p < 0.01$). It is worth noting that these associations do not necessarily reflect the existence of causal relationships, as the study has yet to conduct an empirical assessment of the causal relationships among the variables.

4.2. Panel Cross-Sectional Dependence Testing Results

We conducted a panel cross-sectional dependence test to determine whether cross-sectional connectivity exists among the countries in our panel. We applied four cross-sectional dependence (CD) tests to examine the issue, and the test results are reported in Table 4.

Table 4. Panel cross-sectional dependence test results.

Variable	Breusch-Pagan LM	Pesaran Scaled LM	Bias-Corrected Scaled LM	Pesaran CD	Prob.
$LnCO_2$	21,241.55	658.6719	658.3241	145.5994	0.000 ***
LnNRD	16,984.32	523.5047	523.1568	129.2332	0.000 ***
LnFRD	19,176.46	593.1051	592.7573	138.2965	0.000 ***
LnFDI	4593.015	125.0922	124.7335	60.14498	0.000 ***
LnTO	12,156.16	357.8320	357.4482	108.5687	0.000 ***
LnUPG	9082.746	236.2541	262.8954	85.21947	0.000 ***
LnREC	20,840.47	625.0729	624.7142	143.6616	0.000 ***
LnGDPGR	993.6476	14.32932	13.96265	14.85127	0.000 ***

Source: Authors' compilation from EViews 12 estimations, 2025. Notes: *** for $p < 0.01$; Ln = Natural logarithm operator.

From the results, it can be seen that the probabilities of the test statistics for each variable are statistically significant at the 1% level under each of the four CD tests. This means that the countries in the SSA sample are cross-sectionally connected to one another. The results indicate that any systemic instability occurring in one country can spill over to other countries in the region.

4.3. Panel Unit Root Testing Results

The results in Table 5 indicate that the variables are stationary after converting them to first differences, as evidenced by the more negative test statistics, which are significant at the 1% level. This conclusion is evidenced by the results from both the ref. [33] and ref. [34], wherein the LLC test statistics for CO_2 emissions, for instance, change from −33.1127 at the level with intercept, to −61.6759 at first differencing with an intercept. A similar pattern can be observed for the remaining variables under the LLC computations. Test estimates from the IPS system show the same pattern to the extent that the test values for CO_2 emissions change from −42.6436 at the level with an intercept, to −68.6769 at the first difference with an intercept. The test statistics for each variable follow the observed integration pattern under the two testing regimes, suggesting that our variables are integrated into order one (I(1). The results suggest a possible long-run relationship exists among the variables; therefore, we are justified in conducting a co-integration analysis of the variables.

Table 5. Panel unit root test results.

Test Type	LLC				IPS			
Test Shape	**Level**		**First Difference**		**Level**		**First Difference**	
Variable	**Intercept**	**Intercept and Trend**	**Intercept**	**Intercept and Trend**	**Intercept**	**Intercept and Trend**	**Intercept**	**Intercept and Trend**
$LnCO_2$	−33.1127	−29.1574	−61.6759 ***	−57.4117	−42.6436	−41.2897	−68.6769 ***	−69.3287
LnNRD	−39.8990	−40.2210	−62.3191 ***	−59.4772	−37.3205	−35.9436	−59.5070 ***	−58.8987
LnFRD	−38.7689	−37.1855	−66.4668 ***	−64.6086	−33.7148	−31.4856	−61.9158	−61.4827
LnFDI	−26.4879	−25.5046	−49.8842 ***	−45.5740	−29.0192	−27.6571	−50.2793 ***	−48.4253
LnUPG	−38.5123	−37.2516	−71.0042 ***	−68.5510	−37.2997	−36.3305	−68.0692 ***	−68.3352
LnTO	−26.0690	−22.3430	−40.6395 ***	−36.2354	−30.5830	−27.4841	−44.0995 ***	−41.8860
LnREC	−34.5358	−34.5366	−48.9809 ***	−45.9876	−30.6612	−28.3855	−50.3469 ***	−44.7124
LnGDPGR	−27.2433	−24.4930	−46.3754 ***	−41.5038	−29.0935	−24.8207	−47.5652 ***	−40.7310

Source: Authors' compilation from EViews 12 estimations, 2025. Notes: *** for $p < 0.01$; Ln = Natural logarithm operator.

4.4. Panel Co-Integration Testing Results

After examining the CD and panel unit root properties of the dataset and fulfilling the stationarity condition for conducting panel co-integration analysis, we proceeded to determine co-integration among the variables. The results in Table 6 show the existence of a long-run co-integrating relationship among the variables. Having satisfied important co-integration requirements, we proceeded to analyse the results relative to the objectives of this study.

Table 6. Kao residual panel co-integration test results.

Dependent Variable	CO_2		NRD	
Test Values	**t-Stat**	**Prob.**	**t-Stat**	**Prob.**
ADF	−7.997992	0.0000 ***	−5.192096	0.0000 ***
Residual variance	1.336804		2.650106	
HAC variance	0.664353		1.225758	

Source: Authors' compilation from EViews 12 estimations, 2025. Notes: *** for $p < 0.01$.

4.5. Panel EGLS Cross-Section SUR with the PCSE

Empirical results for our first objective, based on a panel EGLS cross-section SUR with the PCSE strategy, are presented in Table 7. We estimated three econometric models using CO_2 emissions, NRD, and FRD as dependent variables, and FDI as the independent variable. Four control variables (UPG, GDPGR, TO and REC), and one dummy variable, GFC, were included in the regression models. All three models are characterised by acceptable weighted statistics that illustrate the efficiency and quality of the models. For instance, the CO_2 model has an R-squared of 0.699758, an adjusted R-squared of 0.697821, a 1% significant F-statistic, while the Durbin–Watson statistic is 2.044429. Similar weighted statistics define both NRD and FRD models, as shown in Table 7.

The results on how FDI drives environmental sustainability provide theoretically insightful and expected outcomes. This is demonstrated by the positive and significant effect of FDI on two out of the three measures of environmental sustainability. Thus, it is observed that FDI's positive effect on CO_2 emissions is significant at 5% ($\beta = 0.010825$, $p < 0.05$). This means that, holding all other factors constant, a percentage increase in FDI inflows results in a 0.010825% increase in carbon emissions. This result suggests that FDI exacerbates carbon emissions in the selected SSA countries, thereby compromising environmental sustainability. Similarly, the results reveal that FDI has a significant and positive effect on NRD at 1% level ($\beta = 0.030586$, $p < 0.01$). This result also indicates that for every percentage increase in FDI inflows, natural resources are depleted by 0.030586% in the sampled SSA countries, suggesting that FDI contributes to environmental degradation through the exhaustion of natural resource endowments. The results further reveal a positive but statistically insignificant impact of FDI on FRD ($\beta = 0.002278$, $p > 0.1$).

Table 7. Panel EGLS Cross-section SUR with PCSE results.

Model	**Model 1: DV = LnCO$_2$**			**Model 2: DV = LnNRD**			**Model 3: DV = LnFRD**		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Coefficient**	**Std. Error**	**t-Statistic**	**Coefficient**	**Std. Error**	**t-Statistic**
C	0.658344	0.212248	3.101775	−4.528914	0.246000	−18.41023	−3.340853	0.233869	−14.28514
LNFDI	0.010825	0.005411	2.000646 **	0.030586	0.007901	3.871130 ***	0.002278	0.005924	0.384596
LNUPG	−0.183737	0.015828	−11.60843 ***	0.831209	0.026971	30.81897 ***	0.612139	0.022405	27.32193 ***
LNGDPGR	−0.084331	0.007003	−12.04156 ***	−0.036489	0.010201	−3.576896 ***	−0.017728	0.008123	−2.182292 **
LNTO	0.641325	0.035083	18.28001 ***	0.390348	0.044800	8.713105 ***	−0.162083	0.040699	−3.982474 ***
LNREC	−1.021415	0.028860	−35.39209 ***	0.910186	0.023949	38.00582 ***	1.085312	0.026926	40.30794 ***
GFC	0.027395	0.021122	1.297031	0.171333	0.036052	4.752401 ***	0.116016	0.028654	4.048856 ***
R-Squared	0.699758			0.678868			0.694409		
Adjusted R-Squared	0.697821			0.676796			0.692403		
F-Stat.	361.2505			327.6676			346.1545		
Prob. (F-Stat)	0.0000			0.0000			0.000		
Durbin-Watson stat	2.044429			1.853556			1.853752		

Source: Authors' estimations from EViews 12, 2025. Notes: *** for $p < 0.01$ and ** for $p < 0.05$. Notes: DV = Dependent variable; Ln = Natural logarithm operator.

Empirical results detailing the effects of the control variables on measures of environmental sustainability are mixed, with both positive and negative outcomes depending on the specific control variable being considered. For instance, we found that while urbanisation has a significantly adverse effect on CO_2 emissions ($\beta = -0.183737$, $p < 0.01$), its effects on both NRD ($\beta = 0.831209$, $p < 0.01$) and FRD ($\beta = 0.612139$, $p < 0.01$) are positively significant. These results indicate that urbanisation reduces carbon emissions while propelling the depletion of natural and forest resources in the sampled SSA countries. This suggests that the measurement of environmental sustainability defines the extent to which urbanisation's impact can be environmentally devastating or benign.

Similarly, it can be observed that while trade openness has a significantly positive effect on CO_2 emissions ($\beta = 0.641325$, $p < 0.01$) and NRD ($\beta = 0.390348$, $p < 0.01$), its impact on FRD is negative ($\beta = -0.162083$, $p < 0.01$). Consequently, from these results, we realise that, on the one hand, trade openness contributes to soaring carbon emissions and natural resource depletion. On the other hand, it lessens the depletion of forest resources in the SSA region. Therefore, we conclude that the impact of trade openness on environmental sustainability is contingent upon how environmental sustainability is measured.

Equally important observation from Table 7 relates to the effect of renewable energy consumption on environmental sustainability, wherein the 1% statistically significant negative effect of REC on CO_2 emissions ($\beta = -1.021415$, $p < 0.01$) is matched against its positive significant effect on both natural resource depletion ($\beta = 0.910186$, $p < 0.01$) and forest depletion ($\beta = 1.085312$, $p < 0.01$). These outcomes reveal that while the usage of energy renewables facilitates drastic reductions in carbon emissions, the same cannot be said about their consequences on the depletion of natural and forest resources, since both natural and forest resource depletions rather surge with a given unit of utilisation of renewable energy sources. Therefore, the development and implementation of renewable energy policies aimed at addressing environmental problems should be target-oriented.

Furthermore, the results indicate a consistent influence of the global financial crisis (GFC) on all three measures of environmental sustainability, showing a positive effect of the GFC on CO_2 emissions ($\beta = 0.027395$, $p > 0.1$), as well as NRD and FRD. However, it can be ascertained that GFC's effect is significant if we measure environmental sustainability with NRD ($\beta = 0.171333$, $p < 0.01$) and FRD ($\beta = 0.116016$, $p < 0.01$). Thus, the occurrence of the GFC exacerbated the depletion of natural and forest resource endowments in the sampled SSA countries.

4.6. Panel PMG-ARDL Approach

The second part of our study focused on analysing the long-run co-integrating relationship between FDI and the environment, using the PMG-ARDL estimation strategy. With reference to Table 8, we find that for Model 1, the error correction term (ECT) is −1.0091, implying that when the model is in disequilibrium, it is corrected 100.91% within a year. The results are reported in Table 8. For brevity, we limited this section of the analysis to two measures of environmental sustainability (CO_2 emissions and NRD). Evidence of a long-run co-integrating relationship between FDI, environmental sustainability, and the accompanying control variables manifests in the coefficient of the COINTEQN, which has the supposed negative sign and expected statistical significance in both the CO_2 model ($\beta = -1.009109$, $p < 0.01$) and the NRD model ($\beta = -0.968299$, $p < 0.01$). These imply that the variables in the CO_2 model fully converge at a long-run equilibrium following a short-run deviation or disturbance. In contrast, those in the NRD model take approximately 97% to restore the long-run steady state after experiencing a shock in the short-run system of equations. The interpretation is that both models possess a high speed of convergence to the long-run equilibrium condition, with the series in the CO_2 model being very explosive.

Interestingly, FDI does not have a statistically significant relationship with CO_2 emissions in the long run, despite having a positive coefficient ($\beta = 0.005233$, $p > 0.1$). This result suggests that CO_2 emissions in the sampled SSA countries are not accounted for by the incidence of FDI. This finding corroborates ref. [35], who found a positive but insignificant effect of FDI inflows in Africa from 1990 to 2019. The growth of the urban population scaled by GDP has a significantly negative relationship with CO_2 emission, both in the long-run period ($\beta = -0.118628$, $p < 0.01$), and in the short-run period ($\beta = -0.059119$, $p < 0.05$). These statistics suggest that environmental pollution, primarily through carbon emissions, decreases as the urban population expands, and that rapid urban sprawl does not always result in increased air pollution due to carbon emissions. Economic growth's long-run relationship with CO_2 emissions is negative ($\beta = -0.005846$, $p > 0.1$) but statistically not supported; however, in the short run, this relationship is statistically significant ($\beta = -0.011930$, $p < 0.01$). The relationship between trade openness and CO_2 emissions changes from statistically significant and negative in the short run ($\beta = -0.004392$, $p < 0.01$) to statistically significant and positive in the long-run period ($\beta = 0.016212$, $p < 0.01$).

With reference to Table 8, we find that for Model 2, the error correction term (ECT) is -0.9683, implying that when the model is in disequilibrium, it is corrected 96.83% within a year. FDI does not significantly impact environmental sustainability when NRD is used as an alternative measure. In the long-run equation estimation, FDI has a positive long-run relationship with NRD, but this relationship is statistically weak ($\beta = 0.011272$, $p > 0.1$). In the short run, however, FDI's negative relationship with NRD is significant at 10% ($\beta = -0.26959$, $p < 0.1$). According to these results, FDI's contribution to the reduction in depletion of natural resources and, by extension, environmental sustainability, is limited to the short-run period. The growth of the urban population share in the total national population has a statistically significant positive relationship with NRD in the long run ($\beta = 1.906563$, $p < 0.01$). This result indicates that as the processes of urbanisation intensify, natural resource endowments are depleted rapidly in the long term. This relationship is particularly pronounced, given the significant coefficient of UPG in the model. The same cannot be said in the short term, as the positive relationship between UPG and NRD is not statistically significant ($\beta = 0.022543$, $p > 0.1$).

The relationship between economic growth and NRD is observed to be negative at a 10% statistical significance in the long run ($\beta = 0.129078$, $p < 0.1$), but its positive relationship with NRD in the short run appears statistically weak ($\beta = 0.016861$, $p > 0.1$). This means that as the economy grows over the long term, the depletion of natural resources dwindles. The openness of the economy to international trade is also observed to have a weak negative relationship with NRD in the long run ($\beta = -0.011899$, $p > 0.1$), but a strong positive relationship in the short run ($\beta = 0.048759$, $p < 0.01$).

Table 8. Panel PMG-ARDL results.

Model	**Model 1: DV = LnCO$_2$**				**Model 2: DV = LnNRD**			
	Long-Run Equation				**Long-Run Equation**			
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnFDI	0.005233	0.006266	0.835149	0.4038	0.011272	0.072270	0.155967	0.8761
LnUPG	−0.118628	0.019105	−6.209240	0.0000 ***	1.906563	0.282290	6.753915	0.0000 ***
LnGDPGR	−0.005846	0.005450	−1.072684	0.2837	−0.129078	0.075574	−1.707977	0.0879 *
LnTO	0.016212	0.000990	16.37079	0.0000 ***	−0.011899	0.010726	−1.109372	0.2675
	Short-Run Equation				**Short-Run Equation**			
ECT	−1.009109	0.023088	−47.21562	0.0000 ***	−0.968299	0.019173	−50.50365	0.0000 ***
D(FDI)	0.034177	0.010005	3.415903	0.0007 ***	−0.269594	0.141059	−1.911217	0.0562 *
D(UPG)	−0.059119	0.028308	−2.088450	0.0370 **	0.022543	0.115774	0.194719	0.8457
D(GDPGR)	−0.011930	0.004574	−2.608351	0.0092 ***	0.016861	0.070600	0.238822	0.8113
D(TO)	−0.004392	0.001321	−3.325003	0.0009 ***	0.048759	0.008750	5.572498	0.0000 ***
C	0.053300	0.025484	2.091470	0.0367	4.302522	0.323490	13.30034	0.0000

Source: Authors' estimations from EViews 12. Notes: *** for $p < 0.01$; ** for $p < 0.05$ and * for $p < 0.1$. Notes: DV = Dependent variable; Ln = Natural logarithm operator.

4.7. Robustness Checks

We analyse the robustness of the panel PMG-ARDL results using the dynamic panel FMOLS to compare and contrast the two dynamic estimation results. Table 9 displays the numerical results from the dynamic panel FMOLS technique. Based on the FMOLS estimates, it can be seen that FDI has a positive but statistically insignificant relationship with CO_2 emissions ($\beta = 0.017735$, $p > 0.1$), similar to the outcomes from the panel PMG-ARDL model estimator. The negative and significant relationship between urbanisation and CO_2 emissions observed in the PMG-ARDL results is also evident in the panel FMOLS estimates ($\beta = -0.205697$, $p < 0.01$). Similarly, the negative but insignificant relationship between economic growth and CO_2 emissions in the panel PMG-ARDL estimation becomes significant in the panel FMOLS procedure ($\beta = -0.129522$, $p < 0.01$).

Table 9. FMOLS robustness results.

Model	**Model 1: DV = LnCO$_2$**				**Model 2: DV = LnNRD**			
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNFDI	0.017735	0.021134	0.839164	0.4017	0.093624	0.035623	2.628210	0.0088 ***
LNUPG	−0.205697	0.067558	−3.044747	0.0024 ***	1.216427	0.098687	12.32609	0.0000 ***
LNGDPGR	−0.129522	0.037871	−3.420101	0.0007 ***	−0.157663	0.058513	−2.694501	0.0072 ***
LNTO	0.718107	0.037300	19.25217	0.0000 ***	−0.397973	0.059830	−6.651728	0.0000 ***
LNREC	−0.933940	0.045019	−20.74546	0.0000 ***	0.499732	0.068545	7.290540	0.0000 ***

Source: Authors' estimations from EViews 12. Notes: *** for $p < 0.01$; DV = Dependent variable; Ln = Natural logarithm operator.

Again, it can be seen that the positive and significant relationship between trade openness and CO_2 emissions, as observed in the panel PMG-ARDL system, is maintained in the panel FMOLS system ($\beta = 0.718107$, $p < 0.01$). The relationship between REC and CO_2 is significantly negative at 1% ($\beta = -0.933940$, $p < 0.01$). Table 9 provides further evidence of the validity of the results from the panel PMG-ARDL estimator, using NRD as an alternative measure of environmental sustainability. This is because the signage and statistical significance of the parameter estimates from the panel PMG-ARDL system do not depart markedly from those of the panel FMOLS. Clearly, the study can conclude that the dynamic panel PMG-ARDL estimator, which helps us to test the long-run co-integrating relationship between FDI and CO_2 emissions, provides valid and robust results, based on which policy proposals can be made.

The observed empirical results, which explain the positive and significant effect of FDI on CO_2 emissions and NRD, lend support to the pollution haven theory [5,6,16]. Therefore, we fail to reject our first hypothesis, while the second hypothesis can be rejected. This study's findings also align with ref. [24], which provides empirical evidence that FDI leads to the exhaustion of natural resource endowments. However, in terms of carbon emissions and forest resource depletion, this study's findings contrast with those of ref. [24], who report that FDI promotes environmental quality by reducing carbon emissions and forest resource depletion. Analogous findings have been reported in the empirical literature, wherein some studies discovered carbon emissions-enhancing effect of FDI in different geographical locations [21,22]. Prior studies using natural and forest resource depletions as measures of environmental sustainability generally confirm that FDI engenders depletions [17].

Conflicting findings between this study's findings and those of some prior studies are equally available in the literature. For instance, this study's outcomes contradict ref. [35], who found a negative but weak impact of FDI on carbon emissions in G7 economies. Through the lenses of the pollution haven theory, environmental regulations may not be poorly implemented within the G7 economies, and that might have accounted for the

negative but weak impact of FDI on emissions observed by ref. [36], and a possible reason for the differences between this study's outcomes and that of ref. [36].

5. Conclusions and Recommendations

We sought to examine how environmental sustainability is determined by FDI inflows in SSA countries. Prior research has primarily focused on the impact of FDI on environmental sustainability using only CO_2 emissions, which represent only a component of environmental pollution. We addressed this gap by using natural resource and forest resource depletions, as well as CO_2 emissions, as measures of environmental sustainability to ascertain the extent to which FDI affects the environment. We observed that FDI leads to an increase in carbon dioxide emissions, while also contributing to the depletion of natural and forest resources in the selected SSA countries. Our study has extended our empirical understanding of how FDI affects the environment beyond the single indicator of carbon emissions. Our indicators of natural and forest resource depletions help us to account for the depth of FDI's impact on the environment. This demonstrates a new approach towards the measurement of the multidimensional concept of environmental sustainability, which may inform future research designs and policy formulation.

Our findings present an opportunity for policymakers in SSA countries to rethink FDI promotions in the quest to achieve economic growth and sustainable development through FDI inflows. Given the detrimental impact of FDI on the environment, SSA countries need to be cautious in growing their economies in the short term through FDIs to the detriment of the environment, which sustains society in the long term. We argue that building economic wealth through FDI at the detriment of the environment does not demonstrate forward-thinking, social responsibility and generational sustainability; after all, the present generation will not live forever to utilise the accumulated wealth in the long term. Consistent with the findings of this study and those of ref. [37], the need for restrictive policies to contain the environmentally devastating impacts of FDI in SSA countries is long overdue. We are of the opinion that SSA countries need the FDI to complement domestic capital to deliver economic growth; nevertheless, suitable policies are required to limit the negative environmental externalities of FDIs' operations.

In light of the findings, we recommend that FDI promotions be targeted at FDI investors originating from markets with stringent environmental regulations and rigorous enforcement regimes. Such investors are environmentally conscious and have the capacity to responsibly engage in mining activities, for instance. This should be complemented by sound environmental regulation in the FDI destination country. In addition to environmental regulation, taxation regimes must be designed to promote environmental compliance, particularly for investors operating in the extraction sector. Harmonisation of policies at the continental level is of paramount importance in this regard. Policymakers in SSA countries may learn from best practices in legislation development, particularly from the United States of America (USA), Australia, and other developed countries, where legislative instruments covering endangered species, clean water, and biodiversity protection have been developed and implemented.

Despite employing advanced panel econometric procedures, statistical tests, and estimation processes, this study encountered several limitations. First, this study collected yearly data from 47 SSA countries; hence, not all countries in SSA were included in the sample. This may affect the generalisation of the results and findings. Future studies can focus on the moderating role of environmental regulations in the nexus between FDI and environmental sustainability. Furthermore, studies focusing on FDI inflows in challenging territories or regions, such as war-torn and politically unstable regions, would provide novel empirical insights. Likewise, similar to the work of [38], a decomposition of international

capital flows into FDI stock and FDI flows for a comparative analysis approach would better inform macroeconomic policymakers on the appropriate international investment strategies to adopt.

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References

1. Duodu, E.; Baidoo, S.T. The Impact of Capital Inflows on Economic Growth of Ghana: Does Quality of Institutions Matter? *J. Public Aff.* **2022**, *22*, e2384. [CrossRef]
2. Islam, S.N.; Islam, M.S. Friends or Foe? The Complementarity or Substitutability of Financial Development and FDI, Financial Development, and Trade Openness on Domestic Investment. *J. Int. Trade Econ. Dev.* **2023**, *32*, 1083–1111. [CrossRef]
3. Agénor, P.-R.; Montiel, P.J. *Development Macroeconomics*, 4th ed.; Princeton University Press: Princeton, NJ, USA, 1999.
4. Huni, S.; Sibindi, A.B.; Makoni, P.L. Tangible and Intangible Determinants of FDI and FPI Inflows: Evidence from BRICS Countries. *Economies* **2025**, *13*, 353. [CrossRef]
5. Walter, I.; Ugelow, J.L. Environmental Policies in Developing Countries. *Ambio* **1979**, *8*, 102–109.
6. Esty, D.C.; Dua, A. *Sustaining the Asia Pacific Miracle: Environmental Protection and Economic Integration*; Peterson Institute Press: Washington, DC, USA, 1997.
7. Zarsky, L. Havens, Halos and Spaghetti: Untangling the Evidence about Foreign Direct Investment and the Environment. *Foreign Direct Investig. Environ.* **1999**, *13*, 47–74.
8. Eskeland, G.S.; Harrison, A.E. Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis. *J. Dev. Econ.* **2003**, *70*, 1–23. [CrossRef]
9. Tsaurai, K. The Impact of Financial Development on Carbon Emissions in Africa. *Int. J. Energy Econ. Policy* **2019**, *9*, 144. [CrossRef]
10. Tsoy, L.; Heshmati, A. Is FDI inflow bad for environmental sustainability? *Environ. Dev. Sustain.* **2024**, *26*, 28843–28858. [CrossRef]
11. Nasir, N.; Safdar, N. Financial Inclusion, Foreign Direct Investment and Carbon Footprint Nexus in OIC Countries: The Role of Institutional Quality. *Pak. J. Soc. Sci.* **2025**, *45*, 77.
12. Evans, Y. Does Domestic Investment Have a Role in an Economy? An Analysis of the Connection between CO_2 Energy and Growth in the US and Canada. *Forum Sci. Oecon.* **2024**, *12*, 25–50.
13. Renyong, H.; Sedik, A.A. Environmental Sustainability and Foreign Direct Investment in East Africa: Institutional and Policy Benefits for Environmental Sustainability. *Sustainability* **2023**, *15*, 1521. [CrossRef]
14. Saqib, N.; Pinzón, S.; Ozturk, I.; Alam, M.M.; Khudoykulov, K. The dynamic relationship between foreign direct investment and environmental problems in natural resource-abundant countries. *Miner. Econ.* **2025**, 1–25. [CrossRef]
15. Shobande, O.A.; Ogbeifun, L. The Criticality of Financial Development and Energy Consumption for Environmental Sustainability in OECD Countries: Evidence from Dynamic Panel Analysis. *Int. J. Sustain. Dev. World Ecol.* **2022**, *29*, 153–163. [CrossRef]
16. Baumol, W.J.; Oates, W.E.; Bawa, W.S.; Bradford, D.F. *The Theory of Environmental Policy*; Cambridge University Press: Cambridge, UK, 1988.
17. Bokpin, G.A. Foreign Direct Investment and Environmental Sustainability in Africa: The Role of Institutions and Governance. *Res. Int. Bus. Financ.* **2017**, *39*, 239–247. [CrossRef]
18. Zhou, Y.; Fu, J.; Kong, Y.; Wu, R. How Foreign Direct Investment Influences Carbon Emissions: Evidence from Chinese Urban Data. *Sustainability* **2018**, *10*, 2163. [CrossRef]

19. Zafar, M.W.; Zaidi, S.A.H.; Khan, N.R.; Mirza, F.M.; Hou, F.; Kirmani, S.A.A. The Impact of Natural Resources, Human Capital, and Foreign Direct Investment on the Ecological Footprint: The Case of the United States. *Resour. Policy* **2019**, *63*, 101428. [CrossRef]
20. Yu, J.; Majeed, A.; Liu, Y. Rethinking Foreign Direct Investment's Role in Sustainable Development: Insights from the E-7 Economies Using Advanced Panel Data Methodologies. *Sustainability* **2025**, *17*, 3757. [CrossRef]
21. Omri, A.; Ben-Hassen, T. Foreign Investment and Air Pollution: Do Good Governance and Technological Innovation Matter? *Environ. Res.* **2020**, *185*, 109469. [CrossRef] [PubMed]
22. Sarkodie, S.A.; Adams, S.; Leirvik, T. Foreign Direct Investment and Renewable Energy in Climate Change Mitigation: Does Governance Matter? *J. Clean. Prod.* **2020**, *263*, 121262. [CrossRef]
23. Joshua, U.; Festus, V.B.; Sarkodie, S.A. *New Insight into the Causal Linkage Between Economic Expansion, FDI, Coal Consumption, Pollutant Emissions and Urbanization in South Africa*; AGDI Working Paper WP/20/011; African Governance and Development Institute: Yaoundé, Cameroon, 2020.
24. Abayie, O.F.; Duodu, E.; Kwarteng, E.; Frimpong, P.B. Foreign Direct Investments and Environmental Quality in Sub-Saharan Africa: The Merits of Policy and Institutions for Environmental Sustainability. *Environ. Sci. Pollut. Res.* **2021**, *28*, 66101–66120. [CrossRef]
25. Shaari, M.S.; Asbullah, M.H.; Abidin, N.Z.; Karim, Z.A.; Nangle, B. Determinants of Foreign Direct Investment in ASEAN+3 Countries: The Role of Environmental Degradation. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1720. [CrossRef]
26. Amoah, O.J.; Alagidede, P.I.; Awudu, P.S. Impact of Foreign Direct Investment on Carbon Emission in Sub-Saharan Africa: The Mediating and Moderating Roles of Industrialization and Trade Openness. *Cogent Bus. Manag.* **2023**, *10*, 2266168. [CrossRef]
27. Jan, A.; Xin-Gang, Z.; Babar, S.F.; Khan, M.K. Role of Financial Development, Foreign Direct Investment Inflow, and Innovation in Environmental Degradation in Pakistan. *Environ. Sci. Pollut. Res.* **2023**, *30*, 49381–49396. [CrossRef]
28. Pan, X.; Wang, Y.; Tian, M.; Feng, S.; Ai, B. Spatial–Temporal Impulse Effect of Foreign Direct Investment on Intra- and Inter-Regional Carbon Emissions. *Energy* **2023**, *262*, 125438. [CrossRef]
29. Khan, M.N.; Shahbaz, M.; Murshed, M.; Khan, S.; Hosen, M. Does Foreign Direct Investment Influence Carbon Emission-Related Environmental Problems? Contextual Evidence from Developing Countries across Sub-Saharan Africa. *Environ. Sci. Pollut. Res.* **2024**, *31*, 20343–20361. [CrossRef]
30. Dietz, T.; Rosa, E.A. Rethinking the Environmental Impacts of Population, Affluence and Technology. *Hum. Ecol. Rev.* **1994**, *1*, 277–300.
31. Wang, Y.; Ibrahim, R.L.; Oke, D.M.; Al-Faryan, M.A.S. Investigating the Green Energy–Environment Nexus in the Post-COP26 Era. *Int. J. Finance Econ.* **2024**, *29*, 3263–3285. [CrossRef]
32. McCoskey, S.; Kao, C. A Residual-Based Test of the Null of Cointegration in Panel Data. *Econom. Rev.* **1998**, *17*, 57–84. [CrossRef]
33. Levin, A.; Lin, C.-F.; Chu, C.S.J. Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties. *J. Econom.* **2002**, *108*, 1–24. [CrossRef]
34. Im, K.S.; Pesaran, M.H.; Shin, Y. Testing for Unit Roots in Heterogeneous Panels. *J. Econom.* **2003**, *115*, 53–74. [CrossRef]
35. Edeme, R.K.; Israel, I.O.; Emeka, E.T.; Ogochukwu, A.C. Effect of Trade and Industrialisation on Environmental Sustainability: The Case of African Countries. *Foreign Trade Rev.* **2025**, *60*, 33–53. [CrossRef]
36. Nguyen, D.K.; Huynh, T.L.D.; Nasir, M.A. Carbon Emissions Determinants and Forecasting: Evidence from G6 Countries. *J. Environ. Manag.* **2021**, *285*, 111988. [CrossRef] [PubMed]
37. Mundonde, J.; Makoni, P.L. Bridging the Green Infrastructure Gap: Determinants of Renewable Energy PPP Financing in Emerging and Developing Economies. *Sustainability* **2025**, *17*, 9072. [CrossRef]
38. Drob, C.; Plescau, I.; Zichil, V. Foreign Direct Investments and Economic Growth in Romania: A Time-Series Approach for Sustainable Development. *Sustainability* **2026**, *18*, 343. [CrossRef]

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