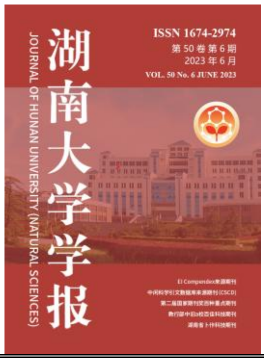

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Financial Development, Foreign Direct Investment, and CO2 Emissions Nexus: Evidence from Sub-Saharan Africa

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Abstract: Studies investigating foreign direct investment in Sub-Saharan African countries focused on the effect on financial development, while ignoring the contributive effect of CO2 emissions and green energy. This study empirically expands its frontier to capture the long-run causal nexus between foreign direct investment and financial development on CO2 emissions and green energy in 47 Sub-Saharan African countries from 1999 to2022 as its primary objectives using the pooled mean group and Dumitrescu and Hurlin panel causality tests. The 47 countries in Sub-Saharan Africa were decomposed into lower-middle, upper-middle, and low-income countries. Empirical results show that financial development positively and significantly influences green energy consumption in sub-Saharan Africa and in various income-level countries. In low-income sub-Saharan African countries, CO2 emissions and financial development had a positive but non-significant long-run nexus. In lower-middle-income SSA countries, CO2 and financial development had a negative and significant nexus. GDP per capita in sub-Saharan African countries and low-income sub-Saharan African countries positively impact green energy. On the contrary, in lower-middle and upper-middle sub-Saharan African countries, the long nexus with green energy is inversely related. The positive long-run nexus between GDP per capita and green energy consumption could be attributable to the fact that most sub-Saharan African countries are not highly industrialized Hence, the heavy reliance on undeveloped machines encourages green energy adoption compared with lower-to upper-middle-income sub-Saharan African countries, where industrialization is the fulcrum of their economic expansion. The research findings support the Pollution Halo Hypothesis and Patrick's stage of the development hypothesis.

Keywords: CO2 emission, green energy consumption, foreign direct investment, sub-Saharan Africa, financial development.

金融发展、外国直接投资和二氧化碳排放的关系：来自撒哈拉以南非洲地区的证据

摘要：调查撒哈拉以南非洲国家外国直接投资的研究重点关注其对金融发展的影响，而忽略了二氧化碳排放和绿色能源的贡献效应。本研究以1999年至2022年47个撒哈拉以南非洲国家为例，利用汇总均值组以及杜米特雷斯库和胡尔林实证扩展了其前沿，以捕捉1999年至

2022年47个撒哈拉以南非洲国家的外国直接投资与金融发展之间的二氧化碳排放和绿色能源之间的长期因果关系作为主要目标。面板因果关系检验。撒哈拉以南非洲47个国家被分为中低收入国家、中高收入国家和低收入国家。实证结果表明，金融发展对撒哈拉以南非洲地区及各收入水平国家的绿色能源消费产生显着的积极影响。在撒哈拉以南非洲低收入国家，二氧化碳排放和金融发展存在积极但不显着的长期关系。在中低收入撒哈拉以南非洲国家，二氧化碳和金融发展存在显着的负相关关系。撒哈拉以南非洲国家和低收入撒哈拉以南非洲国家的人均国内生产总值对绿色能源产生积极影响。相反，在撒哈拉以南非洲的中下和中上国家，与绿色能源的长期联系呈反比关系。人均国内生产总值与绿色能源消费之间的长期正相关关系可能归因于大多数撒哈拉以南非洲国家的工业化程度不高。因此，与低收入和高收入国家相比，对未开发机器的严重依赖鼓励采用绿色能源。撒哈拉以南非洲中等收入国家，工业化是其经济扩张的支点。研究结果支持了污染光环假说和帕特里克发展阶段假说。
关键词：二氧化碳排放、绿色能源消费、外国直接投资、撒哈拉以南非洲、金融发展。

1. Introduction

Over the decades, the African financial system, like most emerging financial systems, has evolved through various restructurings and transition processes from a repressed system to a highly liberalized and stable system to attract international capital flows and technological innovations. The stability of the financial sector is globally considered the fulcrum for inclusive growth and human capital development. The positive and significant role of foreign direct investment, especially for developing economies over the past two decades, is evidenced in several empirical and theoretical studies [1]-[4]. These studies, however, expanded the frontiers to boost productivity and make electricity available to all [5]-[7]. According to the 2018 United Nations report, sub-Saharan Africa (SSA) per capita energy consumption stood at 200 kWh, making it the lowest in the world.

However, this study expands the frontiers to capture the contributive influence of green energy consumption and CO2 emission on foreign direct investment and the financial system in Sub-Saharan Africa. The need to embrace green energy can be attributed to the increasing demand for energy globally to improve productivity and create employment opportunities through small and medium scale enterprises. On the other hand, it is necessary to reduce carbon dioxide emissions (CO2), attract FDI, and bridge the resource gap for economic growth [8]-[11]. As such, previous studies conducted in this area ignored the contributive impact of green energy consumption and CO2 emission.

As posited in [9], a developed and stable financial sector attracts investment into various sectors that lead to eco-friendly growth and CO2 emission reduction through FDI. According to [12], investment in green energy projects in host countries, in particular emerging economies, depends on foreign capital inflow.

In the 1997 Kyoto Protocol Summit for green energy development, government officials, economists and policymakers acknowledged and compelled emerging economies to embrace green energy sources to reduce CO2 emissions [8]. According to [13], an efficient financial market mobilizes and allocates funds to economic agents to invest in eco-friendly skills that reduce CO2 emissions [11], [14]-[15]. Previous studies established that financial development could trigger economic agents’ sensitivity to environmental degradation through good corporate governance [11]. As revealed in [16], stock market regulators are more likely to penalize firms with poor environmental models and give incentives to firms with resourceful eco-friendly policies [17].

In contrast, [9] argued that a sophisticated financial sector would increase CO2 emissions rather than reduce them through energy consumption and industrialization channels. Additionally, [9], [18] and others argued that the mobilization and allocation of financial resources to households, individuals, and businesses enhance their purchasing power to acquire energy-consuming home appliances, production machines, and equipment that increase CO2 emissions, energy consumption, and environmental degradation [9], [19]. According to [20]-[24], financial institutions supporting firms and individuals adopting innovative energy-efficient technologies will increase CO2 emissions. On the other hand, [25] and [26] argued that the negative nexus between industrialization and infrastructure expansion increases CO2 emissions and diminishes green energy consumption. The findings of [27]-[28] among others support these claims.

Notwithstanding, theoretical financial development and CO_2 emissions nexus empirical studies examining the four constructs of the financial system—foreign direct investment, green energy, and CO_2 emissions in SSA, are scanty with diverse results. These diversities in the results are traced to the differences in the economic model, proxies adopted, scope, and study period variations. Some previous studies [30] in emerging economies examined causal linkages in Asia and Latin America.

In other countries, [22] and [30] reported inconclusive results. The lack of consensus in the prior literature infers the need for re-examination to settle the nexus. It is against this lacuna that this study focused on SSA as an emerging region suffering from ecosystem degradation more than industrialized economies [20].

Despite the geometric increase and accompanying economic and technological benefits, [31] revealed that foreign direct investment, in the long run, may diminish the growth potential of the host economy by lowering the balance of payments via profit repatriation, causing social disruptions and negative environmental impacts, and crowding out domestic investment due to multinational enterprises superiority in technology, capital, and managerial skills over their domestic competitors.

This study adopted the dynamic pooled mean group autoregressive distributed lag model (PMG-ARDL) to scrutinize the long nexus between foreign direct investment and the financial system on CO_2 emissions and green energy in SSA. Most previous studies ignored using the classic linear regression model in country-specific studies. This study adds to the extant literature by taking a departure from the study of [21] in BRICS countries, lumping the sample countries together.

According to 33, the smoothing effect from lumping developed and emerging countries together may influence the overall results. This study also takes a departure from the studies in 39 SSA countries from 2004–2014 [33] and in 44 sub-Saharan African countries from 1998-2017 [34].

This study solves these problems and contributes by decomposing the sample population into various income levels countries to access their level of green energy consumption and CO_2 emission in SSA. Using the CIPS and CADF second-generation unit root test and the cointegration technique to scrutinize the cross-sectional interdependence with previous studies also ignored the use of other unit root models. The PMG-ARDL model was adopted to control for endogeneity and serial autocorrelation, and the causality model was adopted to examine the direction of causality [35]. The causality model is considered a superior model to the classical Granger causality test for its ability to account for heterogeneity in data series, along with its reliable and robust test results.

2. Literature Review

2.1. Foreign Direct Investment, Financial Development, and Green Energy Consumption Nexus

Empirically, the financial development and energy consumption nexus recently has received considerable attention but with contradictory results. The study conducted in Yemen [36] revealed that FDI inflow stimulate energy consumption and economic growth. The empirical study [1], among others, collaborates with the findings of [36] in Yemen. In Europe, it was revealed that CO_2 emissions increase as the financial system evolves eventually [27]. In Turkey [38] and in Nigeria [1] the ARDL bound test model was used to observe a positive financial development and carbon emissions nexus in the long run and short run.

Similarly, a negative nexus was reported in the empirical findings of in Indonesia, Malaysia, and Thailand [39]; in the EU [40]; in sectoral studies [41]; in BRICS countries [5], [25], [42], among others, which revealed that FDI inflows diminish energy consumption through the energy technology flow from industrialized economies to developing economies.

Adopting the system GMM model [43], 19 emerging economies from 1990–2013 observed a long-run negative nexus between financial development and CO_2 emissions. As observed in the Chinese provinces [43], CO_2 emissions diminish per capita as the financial system evolves. According to [41], in both the long and short nexus, financial development fails to reduce carbon emissions. However, as argued in [44], using the GMM the financial system-CO_2 emissions nexus is determined by the level of economic-financial system growth in a country. As such, the operational activities of economic agents are eco-friendly at the initial phases of economic-financial system development, but as the economy develops through industrialization, the eco-system is depleted. The findings of [44] support the stage of the development hypothesis in [32].

The findings of [30] in MENA countries support the neutrality hypothesis, stating that the financial system, ecosystem quality, and economic growth nexus are neutral. Theoretically, the Pollution Haven Hypothesis (PHH) explains the FDI-green energy consumption nexus, stating that FDI inflow from developed economies to developing economies increases their profit margin while negatively affecting their profit margin in the country of origin as a result of rigorous ecological laws and compliance costs existing in advanced economies [45].

The Pollution Halo Hypothesis (PH) posits that FDI inflow ought to stimulate green energy consumption due to the inflow of cosmopolitan firms from industrialized economies with stringent ecological laws. As noted in [13], FDI inflow into firms increases their purchasing power to purchase, invest in, and integrate eco-friendly technology into their operational and business activities to reduce CO2 emissions [10], [14]. It can be inferred that as the economy develops, the need for green sources of energy increases.

2.2. The FDI, Financial Development, and CO2 Emissions Nexus

Diverse empirical studies examining this nexus over the period reported divergent results and argued that an increase in economic activity stimulated through FDI inflows causes environmental concerns to become more evident. The Pollution Haven Hypothesis (PHH) revealed that MNCs invest in nations to deoxidize ecological compliance costs and adopt less expensive manufacturing methods that increase CO2 emissions rather than reduce them. Thus, as revealed in [21], FDI inflow increases CO2 emissions in the host countries.

Turkey [46] reported a bidirectional linkage between FDI and CO2, indicating the dependency of the variables. In Azerbaijan, it was observed from 1996 to 2013 that FDI increased environmental pollution using the structural time series model [47]. In China, comparable results were found utilizing the ARDL and non-ARDL models [48]. Upholding the PH argument, [49] noted that FDI inflows instigate investment in green sources of energy and the integration of eco-friendly activities into the operational and business activities of the firm.

As observed in China [50], FDI reduces CO2 emissions using the PCSE estimator. A meta-analysis of 65 primary studies was used in [52], and the positive impact of FDI on environmental quality was reported. Contrarily, empirical studies in Turkey [52] and in North Africa [53], among others, reported a nonsignificant nexus. In South Africa, FDI upsurges CO2 emissions via an economic expansion [54]. In West African countries [21] and [42] in 7 SSA counties, supported the results of [54]. According to [55], in the Middle East and North Africa region, FDI inflow diminishes environmental quality.

3. Methodology

This study adopted the pooled mean group autoregressive distributed lags (PMG-ARDL) model [55] with data sourced from World Development Indicators for 1999-2022. To analyze the financial system, FDI, green energy, and CO2 emission nexus in Sub-Saharan Africa (SSA). This study focused on the 47 SSA countries while decomposing the countries into low, lower, and upper-middle-income groups according to the 2021 World Bank rankings.

Economies with a GNI per capita between \$1,036 and \$4,045 are considered lower-middle-income; GNI per capita between \$4,046 and \$12,535 for upper-middle-income economies; and GNI per capita of \$1,085 or less for low-income economies. The lower-middle-income countries were 18 in the sample, with 6 upper-middle-income countries and 23 low-income countries (Table 1, Panels A and B).

Table 1 Sample countries and description of variables (Compiled by the authors, 2023)

Panel A: Sample SSA Countries (SSA)	
Cabo Verde, Comoros, Congo, Rep, Côte d'Ivoire, Eswatini, Lesotho, Mauritania, Nigeria, São Tomé and Principe, Senegal, Tanzania, Zimbabwe, Zambia, Botswana, Equatorial Guinea, Gabon, Namibia, South Africa, Mauritius, Burkina Faso, Burundi, Central African Republic, Congo, Dem. Rep, Eritrea, Kenya, Ethiopia, Guinea, Guinea-Bissau, Cameroon, Liberia, Malawi, Benin, Mozambique, Niger, Ghana, Rwanda, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, Chad, Gambia, Madagascar, Mali, and Angola	
Lower middle-income countries (SSA-LM): Angola, Benin, Cabo Verde, Cameroon, Comoros, Congo, Rep, Côte d'Ivoire, Ghana, Kenya, Lesotho, Mauritania, Nigeria, São Tomé and Principe, Senegal, Tanzania, Zimbabwe, Zambia, Eswatini	
Upper middle-income countries (SSA-UM): Botswana, Equatorial Guinea, Gabon, Namibia, South Africa, Mauritius	
Low-income countries (SSA-LI): Burkina Faso, Burundi, Central African Republic, Congo, Dem. Rep, Eritrea, Ethiopia, Guinea, Guinea-Bissau, Liberia, Malawi, Mozambique, Niger, Rwanda, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, Chad, Gambia, Madagascar, Mali.	
Panel B: Variable description	
Variables	**Description**
Carbon dioxide emission (CO2 emission)	Oil, gas and other fuels as kg per 2010 US\$ of GDP
Green energy consumption (CEC)	Access to clean fuels and technologies for cooking (% of the population)
Financial development	Private domestic credit (% of GDP) (PDC). Liquid liability (LIQUID) also known as broad money (% of GDP) (MB)
Foreign direct investment (FDI)	Net inflows (% of GDP) (NIF)
Economic Growth (GDP)	GDP per capita (GDP) is a measure of economic growth. Expressed in US dollars and natural logarithm.
The exchange Rate (EXC)	Is measured as the average exchange rate divided by a price deflator
Trade Openness (TOP)	Trade openness measured by Export + Import

3.1. Estimation Procedure

To explore the financial development-foreign direct investment nexus on green energy consumption and CO2 emission, a panel equation was employed and expressed linearly.

$$CEC_{it} = \beta 0 + \beta_1 PDC_{it} + \beta_2 MB_{it} + \beta_3 NIF_{it} + \beta_4 GDP_{it} + \beta_5 EXC_{it} + \beta_6 TOP_{it} + \varepsilon_{it} \quad (1)$$

$$CO2_{it} = \beta 0 + \beta_1 PDC_{it} + \beta_2 MB_{it} + \beta_3 NIF_{it} + \beta_4 GDP_{it} + \beta_5 EXC_{it} + \beta_6 TOP_{it} + \varepsilon_{it} \quad (2)$$

where ε_{it} - error terms, i - cross section, and t - period.

3.2. Cross-Sectional Dependency (CD) Tests

Before investigating the long-run nexus among the study variables, it is significant to investigate the cross-sectional dependance. Studies ignoring the cross-sectional dependance test, according to [21], are more likely to produce spurious results. As a result of globalization and integration [21], [58]. The cross-sectional dependance (CD) test model [59] was adopted and expressed as follows:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \sum_{i=1}^{n-1} \sum_{i=1}^{n-1} (pij)\ N\ (0,1)$$

where N and T - cross-section dimension and period, respectively; p_{ij} - pairwise correlation of the errors.

3.3. Unit Root

The CADF and CIPS unit root models [58] were adopted to check the stationarity properties of the data series. The CADF and CIPS equations are expressed as follows:

$$\Delta Y_{it} = \beta_1 + p_i Y_{it-1} + \beta_{iyit-1} + \sum_{j=0}^{k} Yij\Delta \text{yit} - 1 + \sum_{j=0}^{k} Yij\delta \text{yit} - 1 + \varepsilon_{it} \quad (4)$$

$$\text{CIPS} = \left(\frac{I}{N}\right) \sum_{j=1}^{k} ti\ (N, T) \quad (5)$$

where β_1 - deterministic term k lag order, y_t - cross-sectional mean of time t.

3.4. PMG-ARDL Specification

The specification model is considered a dynamic model for its ability to combine variables that are stationary at diverse orders of integration (I(0) or I(1)) but not I(2). The unit results in Table 2 give our adopted model credibility as they meet the PMG-ARDL estimation conditions. One of the key benefits of this model over others is the ability to overcome the challenges of multicollinearity, heteroscedasticity, endogeneity, and autocorrelation in the model [59]. The equations are expressed as follows:

$$CEC_{it} = \psi_i + \sum_{j=0}^{p} \beta_{ij} CE_{it-j} + \sum_{j=1}^{q} \delta_{ij} F_{it-j} + \varepsilon_{it} \quad (6)$$

$$CO2_{it} = \psi_i + \sum_{j=0}^{p} \beta_{ij} CE_{it-j} + \sum_{j=1}^{q} \delta_{ij} F_{it-j} + \varepsilon_{it} \quad (7)$$

where $F_{it-j} = (PDC_{it} + MB_{it} + NIF_{it} + GDP_{it} + EXC_{it} + TOP_{it} + CEC_{it}$ (in 6), where $F_{it-j} = (PDC_{it} + MB_{it} + NIF_{it} + GDP_{it} + EXC_{it} + TOP_{it} + CO2_{it}$ (in 7); ψ_i - country fixed effect, β_{ij} - CEC or CO2 parameter estimates, δ_{ij} - coefficients of the explanatory variables, and ε_{it} - error term.

Table 2 Descriptive statistics (Compiled by the authors, 2023)

SSA	CEC	CO2	PDC	MB	NIF	GDP	EXC	TOP
Mean	17.955	0.7896	17.229	29.231	4.2878	1755.442	625429.	63.92667
Median	4.200	0.2491	12.510	22.866	2.481103	806.8800	370.424	56.72668
Std. Dev.	24.446	1.5643	16.624	24.151	7.952163	2436.174	2.05008	28.92944
Skewness	1.600	3.6415	2.3066	2.5463	5.935681	3.219803	32.7414	0.878169
Kurtosis	4.751	16.856	9.0203	11.247	55.32006	16.58298	1073.00	3.628359
SSA-LM	**CEC**	**CO2**	**EXC**	**GDP**	**MB**	**NIF**	**PDC**	**TOP**
Mean	22.092	0.5331	161615	1532.640	29.08836	3.689490	17.1778	65.07021
Median	18.025	0.4885	103.055	1321.419	24.90544	1.992922	14.3226	55.93602
Std. Dev.	18.766	0.2900	3.3008	933.3096	18.13826	6.249706	12.3227	30.92474
Skewness	0.9114	0.7190	20.322	1.2802	3.049029	2.752203	2.29385	1.261502
Kurtosis	3.4084	2.7358	414.00	4.5552	14.70795	15.59903	9.71935	4.306590
SSA-LI	**CEC**	**CO2**	**EXC**	**GDP**	**MB**	**NIF**	**PDC**	**TOP**
Mean	3.33250	0.136746	1195.954	542.9053	23.70922	4.744981	10.930	54.70148
Median	1.10000	0.111186	494.7943	480.4386	19.72389	2.746571	9.7519	51.14214
Std. Dev.	7.22593	0.096697	3480.826	336.3360	23.01937	9.400625	7.7216	22.86590
Skewness	5.00187	1.476987	6.256695	2.763001	3.566404	6.313475	0.8932	0.661087
Kurtosis	30.1560	5.566699	46.22854	16.50942	19.00308	53.30628	3.5748	3.566494
SSA-UM	**CEC**	**CO2**	**EXC**	**GDP**	**MB**	**NIF**	**PDC**	**TOP**
Mean	61.59484	4.068827	196.5169	6717.214	48.97291	4.467482	39.80078	90.59917
Median	62.70000	3.065510	20.82454	6289.747	47.04359	3.050146	39.68055	91.46799
Std. Dev.	25.55234	2.522279	261.3509	3428.532	31.96615	6.785842	27.68794	23.00184
Skewness	-0.170968	0.834029	0.796236	1.510284	0.763997	5.625791	0.341726	-0.206551
Kurtosis	1.757023	2.347006	1.779086	6.212830	3.546780	46.64101	2.071397	2.479782

3.5. Dumitrescu and Hurlin Panel Causality Test

To examine the causal-effect nexus among the variables of the study, the panel causality model [35] was adopted. The model is suitable for unbalanced panels and panels with assorted lag orders. The causality test equation is expressed as follows:

$$Y_{it} = \sum_{j=1}^{d} \psi_i(d)\ P_{it-d} + \sum_{j=1}^{d} \beta_i\ (d)\ Z_{it-d} + \varepsilon_{it} \quad (9)$$

where P and Z - PDC, MB, NIF, GDP, EXC, TOP, CEC, and CO2; d - lagged lengths, ψ_i (d) - autoregressive coefficients, β_i (d) - coefficient that allows for difference across the section.

4. Empirical Analysis

4.1. Descriptive Statistics

Table 2 provides both descriptive and inferential statistical summaries, where the mean and median indicate measures of central tendency. From the results, lower-middle-income countries account for the highest standard deviation of 933.309 in GDP per capita in the region, while the full sample (SSA) accounts for 2436.174 in GDP per capita, the lowest in the region. Upper middle-income countries account for the highest standard deviation of 2.522 in the region, and the full sample is 1.564. In upper middle-income SSA countries, financial development proxied by domestic credit to the private sector and liquidity (broad money supply) account for the highest standard deviations of 31.966 and 27.68, respectively, and the full sample accounts for the least carbon dioxide emissions. The results show the financial sector's disparities in SSA, with high consistency in carbon emissions. Skewness measuring the degree of symmetry shows that the variables are positively skewed except for green energy and trade openness.

Low-income countries account for the least CO2 emissions in terms of standard deviation and GDP per capita, and exchange rates here account for the highest standard deviation, implying variation in growth and currency value in these countries. However, the drastic decline in the standard deviation of variables reveals that the higher deviations in SSA are triggered by the merger of countries with enormous divergences in income levels and growth.

4.2. Results of Cross-Sectional Dependance

The results of the cross-sectional dependance test are presented in Table 3. According to [20:58], [21], the negligence of the cross-sectionally-dependent model can lead to spurious results. The results show the cross-sectional dependency among SSA countries. The shock experienced in one nation might quickly spread to other nations in the region.

Table 3 Results of cross-sectional dependence (Compiled by the authors, 2023)

	SSA-UM	**SSA**	**SSA-LI**	**LM**
	Test-Statistic	**Test Statistic**	**Test Statistic**	**Test Statistic**
Breusch-Pagan LM	113.424***	156.462***	108.671***	119.872***
Pesaran scaled LM	17.969***	46.652***	38.901***	43.873***
Bias-corrected scaled LM	17.811***	57.092***	19.895***	32.741***
Pesaran CD	9.7365**	18.725***	12.091***	29.762***

Note: ***** Significance level of 5%

4.3. Unit Root Test (Second Generation)

Before the long-run nexus estimation, the determination of the integration properties of the series is vital to the reliability of the study results. The results reported in Table 4 revealed that the study variables were integrated into diverse orders I(1) and I(0). This result gives credibility to our adopted PMG-ARDL estimation model for testing the long-run nexus.

Table 4 Unit root test results (Compiled by the authors, 2023)

Constant and Trend								
	SSA-UM (CIPS)		**SSA-UM (CIPS)**		**SSA-LI (CIPS)**		**SSA (CIPS)**	
Variables	**Levels**	**Ist Difference**	**Levels**	**Ist Difference**	**Levels**	**Ist Difference**	**Levels**	**Ist Difference**
CEC	-5.345***	-6.876***	-3.812***	-5.812***	0.231	-4.581***	-1.566	-3.901***
CO2	-4.892***	-6.120***	-4.872***	-6.481***	-3.512***	-6.812***	-01.34	-3.982***
PDC	-4.916***	-7.012***	-2.325***	-3.987***	-2.987	-4.875***	-4.012***	-5.546***
MB	-5.900***	-8.762***	-4.812***	-6.152***	-2.489	-4.114***	-3.780***	-4.692***
NIF	-3.235***	-6.710***	-3.587***	-5.701**	-4.781***	-4.903***	-4.811***	-5.901***
GDP	-1.747	-4.388***	-4.802***	-6.126***	-3.781***	-5.901***	-3.700***	-5.590***
EXC	-3.501***	-5.652***	-5.102***	-7.923***	-3.991***	-5.151**	-3.812***	4.671***
TOP	-4.909**	-6.481***	-3.612***	-5.871***	-3.671***	-4.671***	-4.810***	-6.891***
CADF								
CEC	-2.981***	-4.891***	-2.381***	-4.012***	-3.981***	-6.012***	-0.081	-6.012***
CO2	-3.091***	-4.891***	-3.991***	-4.031***	-3.001***	-5.031***	-1.812	-5.031***
PDC	-3.981***	-6.915***	-3.481***	-4.012***	-2.891***	-6.012***	-2.061***	-6.012***
MB	-3.881**	-5.405***	-3.081***	-5.925***	-3.080***	-4.925***	-0.021	-4.925***
NIF	-2.051**	-5.812***	-3.251***	-4.902***	-3.051***	-4.902***	-3.051***	-5.902***
GDP	-1.912	-4.812***	-3.712**	-3.512***	-4.012***	-4.512***	-4.012***	-6.512***
EXC	-0.211	-4.569***	-0.011	-3.069***	-3.011***	-4.069***	-3.011***	-3.069***
TOP	-3.081***	-4.531***	-3.381***	-5.001***	-3.381***	-4.001***	-3.381***	-4.001***

Notes: ****Critical values of CIPS for 1% significance level are -2.250, -3.510, and -2.130; CADF 1% significance level is -2.012, -1.958, and -2.001.

4.4. Co-Integration Test Results

Having established the stationary properties of the series, the co-integrating test nexus was conducted to determine whether there was a long-run equilibrium nexus among the variables of interest using the model of [60] for its capacity to address heterogeneity and interdependence issues. The results are reported in Table 5.

Table 5 Pedroni panel co-integration test results (Compiled by the authors, 2023)

Dependent Variable: CEC					**CO2**			
SSA								
Alternative hypothesis: common AR coefs. (within dimension)					**Alternative hypothesis: common AR coefs. (within dimension)**			
	Statistics	**Prob.**	**Weighted statistic**	**Prob.**	**Statistics**	**Prob.**	**Weighted statistic**	**Prob.**
Panel v-Statistic	1.257064	0.8866	9.415872	0.0000	-0.788347	0.7848	-3.066680	0.9989
Panel rho-Statistic	5.577285	1.0000	6.006090	1.0000	4.473216	1.0000	5.151509	1.0000
Panel PP-Statistic	-1.491907	0.9179	-4.779655	0.0000	-8.086166	0.0000	-4.298696	0.0000
Panel ADF-Statistic	-1.074170	0.9194	-5.867696	0.0009	-6.568743	0.0000	-4.612356	0.0000
Alternative hypothesis: individual AR coefficients (between-dimension)					**Alternative hypothesis: individual AR coefficients (between-dimension)**			
	Statistics	**Prob.**					**Statistics**	**Prob.**
Group rho-Statistic	8.151179	1.0000					0.472331	0.3183
Group PP-Statistic	-4.934798	0.0000					4.577285	1.0000
Group ADF-Statistic	-4.601270	0.0002					-1.491907	0.0679
SSA-UM								
Alternative hypothesis: common AR coefs. (within-dimension)					**Alternative hypothesis: common AR coefs. (within-dimension)**			
	Statistics	**Prob.**	**Weighted statistic**	**Prob.**	**Statistics**	**Prob.**	**Weighted statistic**	**Prob.**
Panel v-Statistic	56.48051	0.0000	8.675884	0.0000	-0.493850	0.6893	-0.969242	0.8338
Panel rho-Statistic	1.424616	0.9229	2.243181	0.9876	2.315863	0.9897	2.277123	0.9886
Panel PP-Statistic	-3.493237	0.0002	-5.315691	0.0001	-1.016018	0.1548	-0.354239	0.3616
Panel ADF-Statistic	-5.385596	0.0000	-6.364576	0.0000	-1.432146	0.0761	-1.588926	0.0560
Alternative hypothesis: individual AR coefficients (between-dimension)					**Alternative hypothesis: individual AR coefficients (between-dimension)**			
	Statistics	**Prob.**					**Statistics**	**Prob.**
Group rho-Statistic	2.869340	0.9979					-0.493850	0.6893
Group PP-Statistic	-7.4064308	0.0000					2.315863	0.9897
Group ADF-Statistic	-6.275595	0.0000					-1.016018	0.1548
SSA-LM								
Alternative hypothesis: common AR coefs. (within dimension)					**Alternative hypothesis: common AR coefs. (within dimension)**			
	Statistics	**Prob.**	**Weighted statistic**	**Prob.**	**Statistics**	**Prob.**	**Weighted statistic**	**Prob.**
Panel v-Statistic	-0.551581	0.7094	0.069041	0.4725	4.774939	1.0000	4.774939	1.0000
Panel rho-Statistic	3.619324	0.9999	3.186856	0.9993	-1.001331	0.1583	-1.001331	0.1583
Panel PP-Statistic	1.459000	0.9277	-0.412134	0.3401	-2.821134	0.0024	-2.821134	0.0024
Panel ADF-Statistic	0.557432	0.7114	-1.777407	0.0378	4.774939	1.0000	4.774939	1.0000
Alternative hypothesis: individual AR coefficients (between-dimension)					**Alternative hypothesis: individual AR coefficients (between-dimension)**			
	Statistics	**Prob.**					**Statistics**	**Prob.**
Group rho-Statistic	4.774939	1.0000					4.774939	1.0000
Group PP-Statistic	-1.001331	0.1583					-1.001331	0.1583
Group ADF-Statistic	-2.821134	0.0024					-2.821134	0.0024
SSA-LI								
Alternative hypothesis: common AR coefs. (within-dimension)					**Alternative hypothesis: common AR coefs. (within-dimension)**			
	Statistics	**Prob.**	**Weighted statistic**	**Prob.**	**Statistics**	**Prob.**	**Weighted statistic**	**Prob.**
Panel v-Statistic	0.472331	0.3183	-1.393303	0.9182	-0.788347	0.7848	-3.066680	0.9989
Panel rho-Statistic	4.577285	1.0000	6.006090	1.0000	4.473216	1.0000	5.151509	1.0000
Panel PP-Statistic	-1.491907	0.0679	-0.779655	0.2178	-8.086166	0.0000	-4.298696	0.0000
Panel ADF-Statistic	-8.342269	0.0000	-1.867696	0.0309	-6.568743	0.0000	-4.612356	0.0000
Alternative hypothesis: individual AR coefficients (between-dimension)					**Alternative hypothesis: individual AR coefficients (between-dimension)**			
	Statistics	**Prob.**					**Statistics**	**Prob.**
Group rho-Statistic	8.151179	1.0000					0.472331	0.3183
Group PP-Statistic	-4.934798	0.0000					4.577285	1.0000
Group ADF-Statistic	-3.601270	0.0002					-1.491907	0.0679

Null Hypothesis: H_0: No co-integration.

From these results, it can be inferred that the null hypothesis of no co-integration is rejected across the categories.

In SSA countries, 5 of the statistical values are statistically significant at 5% with green energy as the dependent variable, and 3 out of the statistical values are statistically significant at 5% and 10%, respectively, with CO2 emission as the dependent variable. Decomposing the SSA countries into low, lower-, and upper-middle-income countries, 4 of the statistical values are statistically significant at 5% with CEC as the dependent variable; 3 statistical values are statistically significant at 5% with CO2 emission as the dependent variable in low-income countries in SSA. CEC is the dependent variable; 3 of the indicators are significant. The overall test results confirm the existence of co-integration among the variables across the study categories.

4.5. Panel PMG-ARDL Results

This study establishes the presence of a co-integrating nexus among the variables using the Pedroni test. The PMG-ARDL model results for the long-run nexus are presented in Table 6.

Table 6 Results of long-run PMG-ARDL estimation (Compiled by the authors, 2023)

Panel A: Long Run Equation								
	SSA		**SSA-LM**		**SSA-UM**		**SSA-LI**	
Variable	**CEC**	**CO2**	**CEC**	**CO2**	**CEC**	**CO2**	**CEC**	**CO2**
NIF	0.237 (7.412)**	0.222 (6.482)**	0.933 (6.194)**	2.785 (11.26)**	0.940 (6.262)**	0.280 (3.969)**	0.645 (5.394)**	0.5151 (3.582)
PDC	0.601 (3.718)**	0.832 (7.914)**	0.363 (5.663)**	0.860 (11.061)**	0.911 (13.396)**	0.950 (5.289)**	0.1140 (2.925)**	0.1239 (8.096)
MB	0.027 (5.509)**	-0.066 (-3.578)**	0.196 (4.543)**	0.4735 (-10.769)**	-0.509 (-0.509)**	0.515 (3.582)**	0.088 (2.813)	0.3135 (5.880)**
GDP	0.352 (5.228)**	0.097 (3.294)**	-0.307 (-4.784)**	-0.546 (-1.782)**	-0.763(-13.279)**	-0.028 (-1.349)	0.104 (5.151)**	0.7552 (11.666)**
EXC	-0.032 (-0.099)**	0.575 (3.597)	0.697 (6.611)	-0.399 (-9.628)**	0.316 (13.032)**	0.123 (8.096)	0.780 (1.568)	0.8250 (2.344)**

Continuation of Table 6

TOP	0.679 (1.599)	-0.480 (-2.641)	0.196 (4.5433)	0.0010 (4.044)**	-0.013 (-2.568)	0.905 (2.739)	-0.058 (-2.149)	0.018 (2.9249)
CEC/CO2	8.579 (125.556)	1.203 (0.596)	10.491 (9.435)	14.681 (7.1001)**	18.192 (4.093)**	6.3233 (3.862)**	6.371 (2.973)**	6.239 (0.8183)
Panel B: Short-Run Equation								
Coint Eq(-1)*	-0.987 (-105.228)***	-0.513 (-6.151)**	-0.888 (-5.762)**	0.738 (6.028)**	-0.618 (-7.872)**	-0.112 (-7.292)**	-0.763 (-13.273)	-0.618 (-7.87)

The PMG-ARDL model results show a positive and statistically significant financial development and carbon dioxide emission long-run nexus and a significantly positive long-run nexus with green energy consumption. This result implies that a 1% increase in financial sector development in SSA would translate to a significant 5% increase in green energy consumption and economic growth, respectively, across the various income groups in SSA, and implies that a 1% increase in financial sector development in SSA would translate to a significant 5% increase in green energy consumption and economic growth, respectively, across the various income groups in SSA. The exchange rate negatively and significantly influences the consumption of green energy.

Similarly, where CO2 is the dependent variable, broad money supply and trade openness negatively influence CO2 emissions in the region, while GDP per capita, FDI net inflow, and private sector credit have a positive and significant impact at a 5% level. This implies that a 1% rise in FDI inflows into the region boosts investment in green energy sources and the integration of eco-friendly activities into the operational and business activities of the firm. This result upholds the PH argument. As observed in China [50], FDI reduces CO2 emissions using the PCSE estimator to improve environmental quality in the country.

In low-income SSA countries, broad money, private sector credit, GDP per capita, FDI, and the exchange rate positively and significantly influence green energy consumption in the long run, while trade openness negatively influences it eventually. With CO2 emissions as the dependent variable, all indicators had a positive impact on the long run. Implying that FDI, financial development, GDP per capita, trade openness, and exchange rates boost green energy consumption in low-income SSA countries while also contributing to an increase in CO2 emissions.

In upper-middle-income SSA countries with green energy consumption as the dependent variable, GDP per capita negatively impacts green energy consumption in the long run at a 5% significance level. On the other hand, with CO2 emission as a dependent variable, all indicators were found to have a positive impact at a 5% significance level. Finally, in low- and middle-income SSA countries with CEC as the dependent variable, financial development and FDI indicators had a significant impact on green energy consumption, with diverse signs.

Results revealed that in middle-income SSA countries, development in the financial sector boosts green energy consumption, while inflows of FDI reduce green energy consumption and GDP per capita. With CO2 emissions as the independent variable, GDP per capita negatively and significantly impacts CO2. This 1% increase in carbon dioxide emissions in these countries reduces their GDP per capita in the long run at a 5% significance level. The short-run error correction model (ECM) results in panel B show that the CointEq(-1) values across the various categories are rightly signed, which is negative and statistically significant, confirming the presence of long-run nexus. The CointEq(-1) value of the various categories indicates the speed of convergence to long-run equilibrium from short-run divergence arising from an increase in CO2 emissions, consumption, and the development of unclean energy, among others.

4.6. Panel Causality Test Results

The heterogeneous causality models [35] were adopted to test for the causal nexus among the variables and series heterogeneity. The test results are reported in Table 7.

Table 7 Panel causality test results (Compiled by the authors, 2023)

Null Hypothesis	**SSA Zbar-Stat**	**SSA-UM Zbar-Stat**	**SSA-LI Zbar-Stat**	**SSA-LM Zbar-Stat**
CEC does not homogeneously cause CO2	4.7900**	5.81074**	6.1261**	8.2012**
CO2 does not homogeneously cause CEC	3.9801**	3.81230**	2.8122**	3.6120**
CEC does not homogeneously cause PDC	2.4158**	3.2160**	2.1008**	3.2683**
PDC does not homogeneously cause CEC	2.5052**	1.5701	2.5625**	3.2260**
MB does not homogeneously cause CEC	0.4013	3.4601**	0.9897	3.0105**
CEC does not homogeneously cause MB	2.0913**	2.9123**	2.3451**	2.5238**
GDP does not homogeneously cause CEC	2.2231**	2.0081**	2.1231**	2.9311**
CEC does not homogeneously cause GDP	3.0129**	0.0536	0.4211	2.1418**
EXC does not homogeneously cause CEC	3.2140**	2.5501**	-0.8475	-0.2907
CEC does not homogeneously cause EXC	3.0531**	4.5127**	-0.8707	-0.6877
TOP does not homogeneously cause CEC	2.0092**	3.1243**	2.4331**	3.5672**
CEC does not homogeneously cause TOP	3.4461**	2.5656**	3.0094**	2.9121**
CO2 does not homogeneously cause CEC	3.3307**	4.9120**	2.2550**	1.3451
CEC does not homogeneously cause CO2	2.4561**	2.4911**	3.9012**	4.5612**
CO2 does not homogeneously cause PDC	2.0123**	3.8912**	3.0907**	2.6012
PDC does not homogeneously cause CO2	2.3451**	0.8321	2.8201**	3.2141**

Continuation of Table 7				
MB does not homogeneously cause CO2	2.1101**	2.0123**	2.7812**	3.4851**
CO2 does not homogeneously cause MB	4.2143**	-0.0101	-0.3432	-0.8213
GDP does not homogeneously cause CO2	3.2128**	2.3401**	2.4210**	4.0128**
CO2 does not homogeneously cause GDP	3.0003**	4.0930**	0.0530	2.4569**
EXC does not homogeneously cause CO2	4.5901**	3.9124**	3.5631**	12.690**
CO2 does not homogeneously cause EXC	3.1102**	2.3451**	2.4511**	11.234***
TOP does not homogeneously cause CO2	-1.15085	-0.3412	-0.2312	-0.9210
CO2 does not homogeneously cause TOP	0.45213	3.4511**	-0.5353	-0.1231**

Note: Significance levels of 5% and 10%

The results in Table 7 demonstrate the degree to which the paired variables of the study assist and/or enhance one another in the growth procedure. A bidirectional causality is where both the probability of causation between the dependent and independent as well as the independent and dependent are significant at a chosen level of significance. When causation is observed in one direction (from dependent to independent or independent to dependent), it is a unidirectional causal nexus. The DH panel causality generator generates individual coefficients. In SSA (SSA-UM, LI, and LM countries), a bidirectional causal nexus between the variables was observed. However, a unidirectional causal nexus was observed among some variables. From the results, it can be inferred that CO2 emissions and CEC cause MB, TOP, EXC, PDC, and GDP. Similarly, a unidirectional causality moved from PDC to CEC, and no causality was observed in SSA. In SSA-UM and SSA-LI, unidirectional causality moving from PCD to CEC was observed at a 5% significance level. Again, in SSA-UM, SSA-LM, and SSA-LI, unidirectional causality flowing from CEC-GDP per capita was observed. In SSA and SSA-LI countries, there is evidence of no causality between TOP and CO2.

5. Discussion

The PMG-ARDL long-run results are presented in Table 7. Financial development had a positive and statistically significant long-run nexus with green energy consumption and CO2 in SSA countries. From the results, it can be inferred that a 1% rise in financial sector development in SSA countries significantly increases green energy consumption and GDP per capita, respectively, at a 5% significance level. Financial system development enhances access to financial resources through its financial intermediation function for households, firms, and individuals to invest in eco-friendly green energy technology projects to reduce CO2 emissions. The results from SSA-UM, SSA-LI, and SSA-LM collaborate with the SSA results in the region and the results [9]-[10], among others. In low-income SSA countries, CO2 and financial development had a positive but non-significant long-run nexus.

In lower-middle-income SSA countries, CO2 and financial development had a negative and significant nexus. The negative and non-significant long-run nexus can be attributed to a lack of political will or low enforcement of environmental compliance policies by corporate bodies and individuals. Since corporate bodies in countries with stringent environmental laws may bribe their way to circumvent the laws in host countries without stringent environmental laws, like most SSA countries, economic growth, proxied by GDP per capita in SSA countries and SSA-LI countries, has a positive impact on CEC. On the contrary, in SSA-LM and SSA-UM, the long nexus with CEC is inversely related. GDP per capita is a key determining element in the quality of an environment.

The inverse nexus can be attributed to economic growth in the SSA region. As economies move toward industrialization, energy consumption demand increases, thus paving the way for the consumption and development of unclean energy in the process of searching for cheaper sources of energy production. In the full sample of SSA countries and decomposed SSA-LI, the positive economic growth and green energy consumption nexus could be because most SSA countries are not highly industrialized. The reliance on an undeveloped operational model encourages green energy adoption compared to lower- and upper-middle-income SSA countries, where industrialization is the fulcrum of economic expansion. The findings of this study support the stages of development hypothesis argument [33] and the findings of [44].

The CO2 and GDP per capita nexus in SSA countries and decomposed SSA-LI countries is positive, implying that a unit rise in economic expansion raises CO2 emissions, exerting a negative effect on the environment. The causality test results revealed a bidirectional, unidirectional, and non-directional causal nexus between foreign direct investment, financial development, green energy consumption, and carbon dioxide emissions in SSA and the decomposition of SSA countries in the region. This supports the findings of [8], [20], [53], [61].

6. Conclusion

Studies examining the FDI-financial development nexus in SAA are numerous. These studies reported mixed results due to different methodological frameworks such as selective sample, time span, econometric modeling and failure to account for heterogeneous growth patterns in SSA countries.

In addressing this gap, this expanded the frontiers to capture the effect of CO2 emission and green energy consumption in Sub-Sharan countries and further decomposed the 47 countries into low-income, lower-middle-income, and upper-middle-income countries to scrutinize the nexus from 1999 to 2022.

FDI-financial development is heavily touted as a developmental catalyst. As a result, it paves way for emerging economies to yean for FDI and financial development to improve and invest in green consumption and reduce CO2 emissions. In a bid to attract sufficient FDI inflow into SSA, the effect on the ecosystem should not be ignored.

The global concern about the relationship between growth and the environment as well as the need to understand FDI inflow and financial development growth models in SSA countries and their consequences on the environment through CO2 emission and green energy consumption continues to interest scholars and policymakers.

In SSA countries, studies examining the FDI-financial development nexus reported mixed results while ignoring the effect on the ecosystem through CO2 emission.

This study employed the PMG-ARDL model on 47 SSA countries from 1999 to2022 as the main sample. The study further decomposed the sample into lower-middle, upper-middle, and low-income countries to determine the contributive effect of various income levels in this nexus.

In investigating the FDI-Financial development long-run nexus on CO2 emission and green energy consumption, the PMG-ARDL estimator was used after establishing stationarity at various orders of integration I(1) and I (0) using CIS and CADF, which are robust to the existence of cross-sectional interdependence. Besides, a causality test developed by Dumitrescu and Hurlin was used to establish a pairwise link between all variables.

Empirical results showed a positive and significant long-run causal nexus between CO2 emissions and CEC. Bidirectional and unidirectional causal nexus were also observed. This study recommends, among other things, the deepening of the financial system in the 47 SSA countries under study.

To boost economic growth and access to financial resources for investment in eco-friendly green energy technology through low-cost credit facilities improve the quality of the ecosystem in the region. Implying a shift from traditional energy sources to renewable energy sources. This finding gives more support to the SSA countries policy shifts from traditional energy to renewable energy as a means to improve the environment.

We urge that governments in SSA to increase their investments in renewable energy sources. The investment could be infrastructure investment via green job creation for the green production process and a shift from electricity consumption to hydropower, wind energy and solar energy leading to the transition to renewable energy. Uniform policies to promote and reduce CO2 emission should be developed in the region. However, there is a need for tax incentives for financial institutions that provide adequate credit services for green projects and borrowers with higher environmental compliance in their operational and business activities.

In a bid to ensure a safe and eco-friendly investment climate, this study also recommends, among other things, the embrace of FDI from countries with stringent environmental laws to allow for inflows of such compliance, since general inflows can instigate CO2 emission increases in SSA countries. However, corporate bodies and individuals from countries with stringent environmental laws may bribe their way to circumvent the laws in host countries without stringent environmental laws, as in most SSA countries. The Pollution Haven Hypothesis supports this recommendation, stating that most corporate bodies and individuals consider emerging and developing economies as lawless, corrupt, and damping sites for industrial businesses without regard for the ecosystems of the host countries.

FDI inflows from countries with stringent environmental laws will enhance investment in the development and consumption of green energy sources in SSA countries in the region.

The CointEq(-1) values indicate the speed of convergence to long-run equilibrium from short-run divergence arising from an increase in CO2 emissions, consumption, and the development of unclean energy, among others, in SSA countries.

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