



Revisiting the Environmental Kuznets Curve (EKC) Hypothesis: Empirical Evidence from Selected Sub-Saharan African Economies in the Context of Sustainable Development

ISIBOR BRITNEY OSAIGBOVO, UMORU TIJANI SHEHU
University of Benin, Benin City, Nigeria

Abstract. This study revisits the Environmental Kuznets Curve (EKC) hypothesis within the context of sustainable development in Sub-Saharan Africa (SSA), focusing on the relationship between economic growth, financial development, and environmental degradation. Drawing on panel data from seven purposively selected SSA countries—Côte d'Ivoire, Ghana, Kenya, Mauritius, Namibia, Nigeria, and South Africa—spanning the period 1993 to 2021, the study employs the Autoregressive Distributed Lag (ARDL) approach using Pooled Mean Group (PMG) estimation to capture both short-run and long-run dynamics. Environmental degradation is measured through three proxies: carbon dioxide (CO₂) emissions per capita, ecological footprint per capita (EFPC), and the ecological footprint index (EFPI). Control variables include energy consumption, foreign direct investment (FDI), urbanisation, and secondary school enrolment. Panel unit root and Pedroni cointegration tests confirm the presence of long-term relationships, while Granger causality tests explore the direction of causality between GDP per capita and environmental indicators. The findings support a cubic (N-shaped) EKC relationship across all three measures of environmental degradation, indicating that environmental quality initially worsens with rising income, improves after a threshold, but may deteriorate again at higher income levels. Additionally, energy consumption significantly contributes to CO₂ emissions and EFPC, while FDI and urbanisation exert mixed effects depending on the environmental metric. The error correction models show significant adjustment toward long-run equilibrium for CO₂ and EFPC, but not for EFPI, underscoring the persistent nature of broader ecological stress. Based on these findings, the study recommends region-specific policies that prioritize renewable energy investment, green urban infrastructure, and sustainable FDI flows, along with human capital development through expanded

access to quality education, to ensure environmentally sustainable growth in SSA.

1. Introduction

In recent decades, environmental degradation has emerged as one of the most pressing global challenges, drawing considerable scholarly and policy attention. Central to this issue is the increasing emission of greenhouse gases (GHGs), particularly carbon dioxide (CO₂), which is the most significant contributor to anthropogenic climate change, accounting for over 60 percent of the enhanced greenhouse effect (Acaravci & Ozturk, 2010). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2014) documented a significant rise in CO₂ emissions per unit of GDP since the 1970s, indicating that economic expansion has often come at the cost of environmental sustainability. Consequently, a growing concern for policymakers has been how to reconcile environmental protection with sustained economic development (Bacon & Bhattacharya, 2007; Majeed & Mazhar, 2019).

One prominent framework for exploring this complex relationship is the Environmental Kuznets Curve (EKC) hypothesis, originally derived from Kuznets' (1955) income-inequality curve. The EKC posits an inverted U-shaped relationship between environmental degradation and income per capita, suggesting that environmental degradation initially rises with economic growth but begins to decline after surpassing a certain income threshold. The theoretical underpinnings of this relationship are attributed to the scale effect (early industrial growth increasing pollution), composition effect (structural shifts from manufacturing to services), and technique effect (adoption of cleaner technologies at higher income levels) (Grossman & Krueger, 1995). This hypothesis has been widely tested across economies with varying results, with some studies

confirming its validity (Shahbaz et al., 2012; Tiwari et al., 2013; Sinha & Sen, 2016), while others reject it, arguing that economic growth continues to degrade environmental quality (Dogan & Ozturk, 2017; Nassani et al., 2017; Sinha et al., 2017).

Despite this wealth of literature, much of the empirical testing of the EKC hypothesis in Sub-Saharan African (SSA) countries remains limited and inconclusive. Previous studies suffer from various methodological limitations, including reliance on CO₂ emissions as the sole indicator of environmental degradation, use of polynomial specifications prone to multicollinearity, and estimation techniques that ignore parameter heterogeneity across countries (Al-Mulali et al., 2015; Gao & Zhang, 2014; Egbetokun et al., 2019). CO₂ emissions alone provide a narrow view of environmental harm, failing to capture the broader ecological footprint that encompasses resource consumption and waste generation (Majeed & Mazhar, 2019). Furthermore, polynomial models, which include squared and cubic GDP terms to test the EKC, often result in spurious relationships due to high multicollinearity, thus undermining the reliability of policy implications derived from such models.

This study addresses these gaps by employing a robust and parsimonious empirical framework to test the EKC hypothesis in selected SSA countries using both carbon dioxide emissions per capita and ecological footprint per capita as indicators of environmental degradation. Ecological footprint provides a more comprehensive measure of human pressure on the environment, capturing not only emissions but also land and water use, thereby offering a broader view of environmental sustainability (Al-Mulali et al., 2015; Khuky, 2021). Methodologically, the study adopts the Auto-Regressive Distributed Lag (ARDL) framework within a panel setting using both the Pooled Mean Group (PMG) and Mean Group (MG) estimators (Pesaran, Shin & Smith, 1999). These techniques are superior to conventional fixed and random effects models as they account for cross-country heterogeneity and provide reliable long- and short-run parameter estimates. In line with the non-polynomial specification proposed by Narayan & Narayan (2010), the study infers the presence of an EKC if the short-run income elasticity of emissions is positive and the long-run elasticity is negative and statistically significant.

By applying these methodological advances and utilizing a broader set of environmental indicators, this study contributes to the literature by generating more reliable and policy-relevant insights into the income-environment nexus in Sub-Saharan Africa. The findings have critical implications for

environmental sustainability strategies in the region, particularly in light of global efforts to achieve the United Nations Sustainable Development Goals (SDGs) and the climate targets under the Paris Agreement.

The remainder of the paper is structured as follows. Section 2 presents the literature review. Section 3 outlines the methodology and model specification. Section 4 discusses the empirical results, and Section 5 concludes with conclusion and recommendations.

2. Literature Review

2.1 Environmental Degradation

Environmental degradation refers to the sustained deterioration of the environment through the depletion of natural resources, disruption of ecosystems, and loss of biodiversity, leading to reduced environmental quality and sustainability (Brown et al., 1987; Johnson et al., 1997). It encompasses phenomena such as soil erosion, desertification, deforestation, air and water pollution, loss of flora and fauna, and rising global temperatures due to greenhouse gas emissions. The process is both a cause and consequence of unsustainable human activities, particularly in the context of rapid industrialization and urban expansion (Malcolm & Pitelka, 2000; Maurya et al., 2020).

In Sub-Saharan Africa (SSA), environmental degradation poses a unique challenge. Despite contributing only about 4% of global CO₂ emissions (Ayompe, Davis & Egoh, 2020), the region is disproportionately affected due to its high dependence on climate-sensitive sectors like agriculture and forestry, low adaptive capacity, and persistent socioeconomic vulnerabilities (World Bank, 2012; Babatunde, 2014). Rapid population growth, increasing urbanization, and unsustainable land use practices exacerbate the environmental crisis in many SSA countries (Neumayer, 2002; Osabuohien et al., 2014).

According to Aduebe (2013), environmental degradation results from the unsustainable exploitation of biotic and abiotic elements of the environment ranging from soil and water to wildlife and atmospheric gases. This conceptualization is further extended by Chopra (2016) and Conserve Energy Future (2020), who define degradation as any anthropogenic change in the environment considered undesirable or harmful, particularly those associated with unsustainable resource use and pollutant discharge.

There are various measures of environment degradation, including Carbon Dioxide (CO₂) Emissions, and Ecological Footprints.

Carbon Dioxide (CO₂) Emissions

Carbon dioxide (CO₂) emissions are widely regarded as a core indicator of environmental degradation due to their pivotal role in climate change. CO₂, a colorless and odorless gas, is primarily emitted through the combustion of fossil fuels (coal, oil, and natural gas), industrial production, and land-use changes such as deforestation (IPCC, 2018; Gasser & Luderer, 2018). According to Eurostat (2017) and the World Bank (2018), CO₂ emissions also include those generated from cement manufacturing and gas flaring and are typically measured in metric tons per capita.

The centrality of CO₂ in discussions of environmental degradation lies in its characterization as the most significant anthropogenic greenhouse gas. While other gases such as methane (CH₄), nitrous oxide (N₂O), and ozone also contribute to the greenhouse effect, CO₂ accounts for approximately 74% of global greenhouse gas emissions (Climate Watch, 2021). The Kyoto Protocol and subsequent international agreements, such as the Paris Agreement, have institutionalized CO₂ reduction targets to mitigate climate-related risks (Brander, 2012).

To facilitate comparison of various greenhouse gases, the concept of carbon dioxide equivalent (CO₂e) is used. This metric expresses the amount of CO₂ that would have an equivalent warming effect as other greenhouse gases, thus standardizing emissions data and improving policy responses (Mackay, 2008; Brander, 2012). For example, one kilogram of methane (CH₄) is approximately equivalent to 25 kilograms of CO₂ in global warming potential.

Ecological Footprint

The ecological footprint is a broader and more systemic indicator of environmental degradation that complements emission-based metrics. It measures the biologically productive land and water area required to produce the resources consumed and absorb the waste generated by a population, given prevailing technology and resource management practices (Al-Mulali & Sheau-Ting, 2014; Jović et al., 2018). It includes multiple components such as cropland, grazing land, forest products, fishing grounds, built-up land, and the carbon footprint.

This measure is particularly relevant for SSA, where high levels of dependence on natural resources for livelihoods, combined with inadequate

infrastructure and poor waste management systems, lead to overexploitation and environmental strain (Uddin et al., 2017; Majeed & Mazhar, 2019). The ecological footprint is expressed in global hectares (gha) per person and serves as a benchmark for comparing natural resource consumption against the Earth's regenerative capacity (Charfeddine & Mrabet, 2017; Aydin et al., 2019).

Unlike CO₂ emissions, which focus on air pollution, the ecological footprint provides a holistic view of human demand on ecosystems. As such, it is increasingly adopted in sustainability assessments to capture the cumulative environmental pressures of development processes.

2.2 Economic Growth

Economic growth refers to the sustained increase in a country's capacity to produce goods and services, driven by technological progress, institutional evolution, and broader economic development. As described by Kuznets (in Todaro, 1985), it involves not just quantitative expansion, but also qualitative transformation in production and distribution. Scholars such as Burda and Wyplosz (2005), Todaro and Smith (2006), and Olowofeso et al. (2015) emphasize that economic growth manifests through rising GDP, per capita income, and overall improvements in national productivity and the capacity to meet consumer demand, often achieved through innovation and scaling up of production.

However, the process of economic growth can have complex implications for environmental quality. Initially, growth may lead to environmental degradation due to increased input use and industrial expansion (scaling and composite effects). As economies shift from agriculture to industry and eventually to services, environmental pressures may decline, especially with the adoption of cleaner technologies (Stern, 1998; Stokey, 1998). Yet, in its early stages, growth tends to accelerate resource use and emissions, particularly in developing economies, leading to a decline in environmental health (Bloach, Zhang & Iqbal, 2019). In empirical analysis, GDP per capita remains a principal metric for assessing economic growth and its environmental consequences.

2.3 Theoretical Framework- The Environmental Kuznet Curve

The Environmental Kuznets Curve (EKC) hypothesis remains a central framework in analyzing the relationship between environmental degradation and economic growth. This hypothesis posits that at the early stages of economic development, environmental degradation intensifies as income rises, but after reaching a specific threshold—referred to as the turning point—further increases in

income lead to improvements in environmental quality. This relationship is commonly illustrated as an inverted U-shape, where environmental harm initially increases with per capita income but subsequently declines beyond a certain income level. Thus, in a nation's development trajectory, environmental conditions worsen before improving as income per capita continues to rise.

The EKC can also be understood through the lens of structural economic transformation. As shown in Figure 1, the progression from a pre-industrial to an industrial economy is typically associated with environmental decline due to the increasing dominance of capital-intensive industrial activities and the diminishing role of agriculture. This industrial shift fosters productivity, income growth, and higher levels of consumption. However, as economies evolve into post-industrial stages, a transition occurs in which the service sector expands, the share of industrial output declines, and societies begin to prioritize environmental health. At

this juncture—the turning point represented in Figure 2.1—environmental degradation begins to recede as cleaner technologies and regulatory frameworks become more prevalent (UNCTAD, 2012).

Figure 1 also visually depicts the initial phase of development, where environmental degradation primarily stems from agricultural and resource-based subsistence activities, albeit at relatively lower levels of intensity. As industrialization accelerates, resource extraction and waste generation increase significantly, corresponding to the upward slope of the curve. In the later stages of development, technological advancements, service-oriented growth, and societal demand for improved environmental standards result in a downturn in environmental degradation. Hence, the downward slope of the EKC reflects the eventual decoupling of economic growth from environmental harm (Moomaw & Unruh, 1997; Panayotou, 2003).

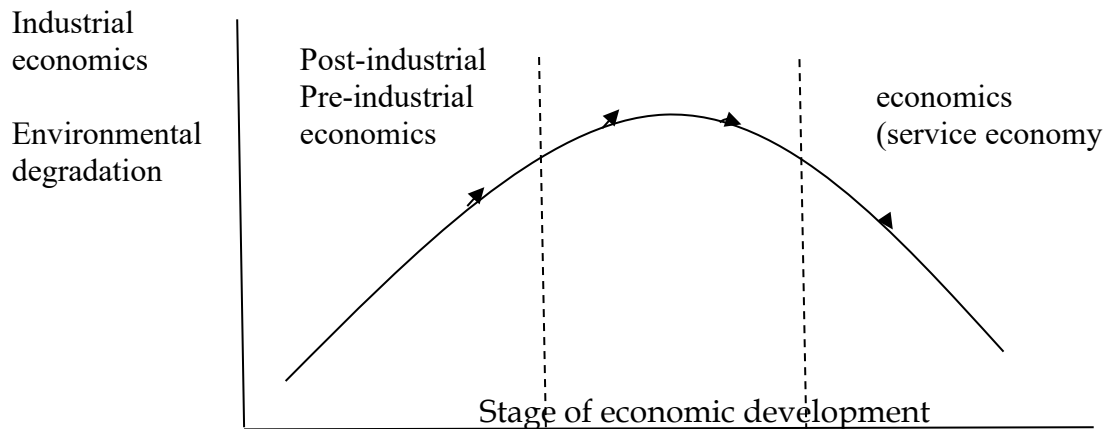


Figure 1: The shape of the EKC
Notes: The horizontal axis is income per capita.
Source: Panayotou (2003:46)

The notion that environmental quality functions as a luxury good influences the shape of the Environmental Kuznets Curve (EKC). At the early stages of economic development, individuals are less inclined to forego immediate consumption for investments in environmental preservation. As income levels rise and basic needs are met, societies begin to demand cleaner environments, leading to increased public and private investments in environmental quality. This shift in societal preferences results in a decline in environmental degradation beyond a certain income threshold, thereby creating the downward slope observed in the latter stages of the EKC (Moomaw & Unruh, 1997; Galeotti, 2003) as illustrated in Figure 1.

Another interpretation of the EKC's curvature is rooted in demographic and structural shifts

associated with economic growth. As countries become wealthier, they typically experience demographic transitions marked by lower fertility rates and higher levels of education, which slow population growth and alleviate pressure on natural resources. Early stages of economic development are often associated with resource-intensive industrialization, contributing to environmental harm. However, as nations progress, they begin to adopt cleaner technologies and implement more stringent environmental regulations, ultimately leading to improvements in environmental quality (UNCTAD, 2012).

From a more optimistic perspective, the EKC hypothesis posits that economic growth may intrinsically resolve environmental issues. This view suggests that as nations become wealthier, policy

reforms and technological innovations will naturally arise to address environmental degradation, thereby making environmental improvement a byproduct of continued economic expansion (Roca et al., 2001; Perman & Stern, 2003). Nonetheless, this interpretation may be overly simplistic. Environmental quality is shaped not only by current levels of emissions or pollutants but also by the cumulative impact of past environmental stresses. As Arrow et al. (1995) caution, economic growth alone cannot guarantee environmental sustainability, nor should it be viewed as the principal mechanism for achieving ecological balance.

The Shape of the EKC

The conventional Environmental Kuznets Curve (EKC), as depicted in Figure 1, has faced significant criticism both as a theoretical model and a practical policy guide. Critics argue that the model may inadvertently promote a ‘pollute now, clean later’ approach, especially in developing countries where immediate economic concerns like employment and income often overshadow environmental considerations (Dasgupta et al., 2002). The underlying assumption that wealthier populations inherently value environmental quality more than poorer ones is also not conclusively supported by empirical evidence (Martinez-Alier, 1995; Kriström & Riera, 1996). Consequently, this challenges the deterministic interpretation of the EKC and implies that effective environmental protection policies can be enacted at any development stage (Neumayer, 2002).

With increasing awareness and public concern about environmental quality, especially in developing economies, it is conceivable that countries may avoid the steep environmental degradation suggested by the original EKC. Through proactive environmental enforcement and policy innovation—potentially even without comprehensive regulatory frameworks—some countries may achieve higher income levels with minimal ecological harm. This implies a lower and flatter EKC trajectory than that predicted by the traditional model, indicating that environmental improvements could coincide with early stages of growth (Dasgupta et al., 2002). Therefore, the static nature of the EKC form is increasingly being questioned in recent literature.

Accordingly, the EKC framework now includes three major variants: the traditional EKC, the generalized EKC, and the updated EKC, with the latter assumed to be flatter. Emerging empirical evidence contests the foundational assumption of the original EKC—that low-income countries lack environmental governance capacity. Instead, revised models suggest that pollution levels begin to decline earlier in the development process due to better policy responses and technological adaptation. As illustrated in Figure 2, this version of the EKC shows environmental degradation peaking at a lower income threshold compared to the traditional model. Studies by Dasgupta et al. (2004), Piaggio & Padilla (2012), and Al-Sayed & Sek (2013) confirm this evolving EKC form, emphasizing the need for a more flexible, context-sensitive interpretation of the environment-growth relationship.

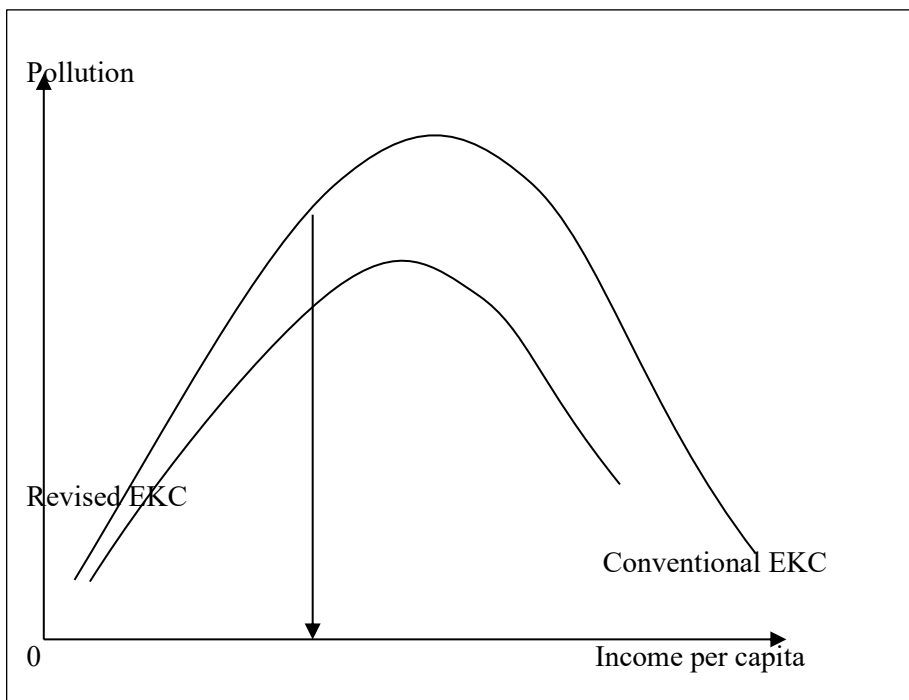


Figure 2: Revised and Conventional EKC
 Source: Dasgupta et al. (2002:148)

Some researchers, such as De Bruyn et al. (1998), contend that the Environmental Kuznets Curve (EKC) may not be valid over the long term. They argue that while the initial relationship between economic growth and environmental degradation may follow an inverted U-shape, this pattern does not persist indefinitely. At higher income levels, a new inflection point may emerge, causing environmental degradation to rise once again, thereby forming an N-shaped curve (Carvalho & Almeida, 2010). This implies that after initial improvements in environmental quality, further economic expansion could lead to renewed environmental harm.

This more complex trajectory is referred to as the "generalized EKC" by Moomaw and Unruh (1997). It captures the possibility of multiple turning points along the income-environment relationship. Figures 3 and 4, as illustrated by Moomaw and Unruh (1997) and Carvalho and Almeida (2010), respectively, depict this N-shaped dynamic. In this framework, each point where the direction of environmental impact shifts in response to income growth is known as a turning point.

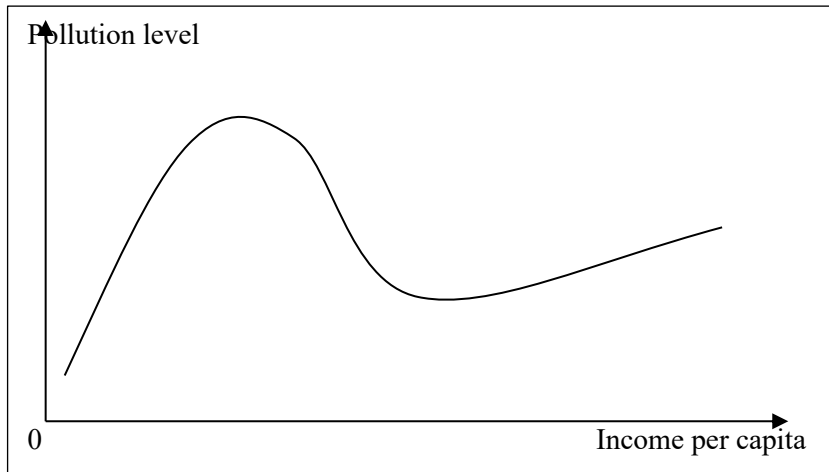


Figure 3: Generalised EKC
Source: Moomaw and Unruh (1997:3)

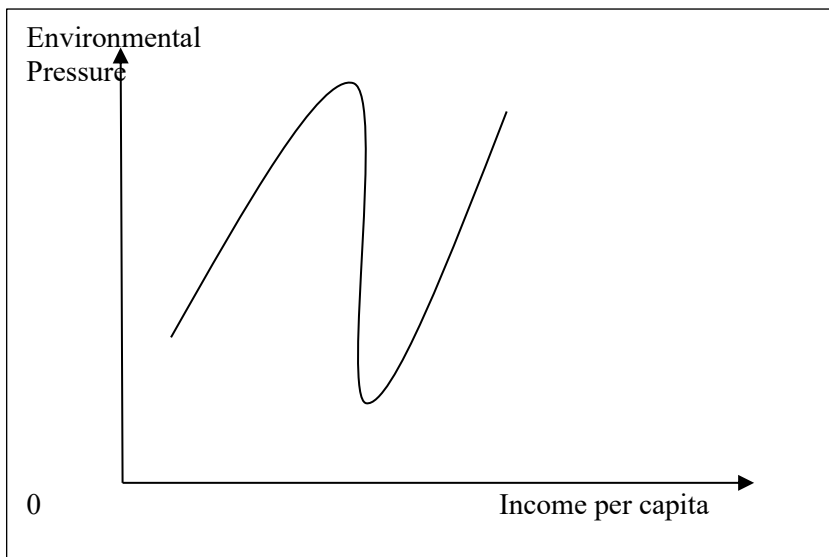


Figure 4: N-shaped curve
Source: Carvalho & Almeida (2010:4)

From an economic standpoint, carbon dioxide (CO₂) was historically not considered a waste product due to its colorless and odorless nature. However, modern scientific evidence confirms that CO₂ is indeed a byproduct of numerous anthropogenic activities. Global emissions of CO₂ resulting from human actions have increased significantly, with an annual growth rate rising from 1.1% in the 1990s to

3.8% between 2002 and 2011 (Granados & Carpintero, 2009; PBL & JRC, 2014). Unlike localized pollutants such as sulphur dioxide or particulate matter, CO₂ is a transboundary pollutant with global implications. This makes the social costs of climate change more complex, as they are distributed across both time and geography. Consequently, the Environmental Kuznets Curve

(EKC) hypothesis is generally seen as less applicable to CO₂ emissions compared to localized pollutants, primarily due to the pronounced free-rider problem associated with global pollutants (Galeotti, 2003; Carvalho & Almeida, 2010).

Empirical studies have presented mixed evidence regarding the EKC's applicability to CO₂. Some researchers, such as Shafik (1994) and De Bruyn et al. (1998), have observed a positive linear relationship between GDP per capita and CO₂ emissions, indicating no turning point, thus challenging the EKC hypothesis. Others suggest that the relationship might be N-shaped or cubic, as proposed by Holtz-Eakin and Selden (1995) and Moomaw and Unruh (1997), implying that CO₂ emissions may initially fall but rise again at higher income levels. Such findings cast doubt on the optimistic interpretation that economic growth naturally leads to environmental improvement (Friedl & Getzner, 2002).

Nevertheless, a number of studies have identified the EKC pattern even for CO₂ emissions. For instance, Sengupta (1996), Galeotti et al. (2001), and Pauli (2003) reported evidence of an EKC for CO₂. Schmalensee et al. (1998) also confirmed the EKC trend for CO₂ during 1950–1990 and projected its continuation into the future. However, similar inconsistencies have been observed in the case of local pollutants—while Panayotou (1997) validated the EKC for sulphur dioxide and particulate matter, Selden and Song (1994) reported an N-shaped pattern. These contradictions suggest that the EKC is not universally applicable, and it remains contentious whether sustained economic growth inherently leads to environmental improvement.

2.4 Empirical Perspectives on Testing the Environmental Kuznets Curve (EKC) Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis—which posits an inverted U-shaped relationship between environmental degradation and income per capita—has been subjected to rigorous empirical testing across various economic contexts. In developed countries, the evidence is mixed, with several studies confirming the EKC while others suggest more complex or even contradictory patterns. Grossman and Krueger (1991, 1993) were among the first to identify an inverted U-shaped relationship between economic growth and pollutants such as sulfur dioxide and suspended particulate matter in the United States, estimating turning points around \$4,000–\$5,000 (1985 USD). Similarly, Selden and Song (1994) identified turning points above \$8,000, indicating that environmental improvements begin only at higher income levels. Moomaw and Unruh (1997) extended the analysis to

16 OECD countries and found a statistically significant N-shaped relationship, reflecting possible environmental degradation resurgence at high-income levels. Friedl and Getzner (2003) and Galeotti and Lanza (2003) also supported the EKC in Austria and other OECD nations, though highlighting the superiority of cubic over quadratic specifications. However, not all developed economies show conformity. Esteve and Tamarit (2012) found no EKC evidence in Spain, while Huang et al. (2008) demonstrated that compliance with the Kyoto Protocol did not uniformly validate the EKC among Annex II countries.

In developing countries, the EKC hypothesis exhibits even more heterogeneity. Narayan and Narayan (2010), using income elasticities, supported the EKC in 35% of 43 developing countries. For instance, Aduobe (2013) and Shahbaz et al. (2012) confirmed the EKC in Nigeria and Pakistan, respectively. Contrastingly, Akbostanci et al. (2009) and Alam et al. (2016) did not find support for the EKC in Turkey and India, respectively. Furthermore, several studies emphasized the role of trade openness and urbanization in mediating the income-environment nexus. For example, Saboori et al. (2012) and Tiwari et al. (2013) confirmed the EKC in Malaysia and India, attributing emissions mainly to trade and fossil energy use. Gao and Zhang (2014) found the EKC to hold in Sub-Saharan Africa using electricity consumption data, while Ben-Jebli et al. (2015) reported its absence using trade-adjusted models. Additional studies, such as Kwakwa and Adu (2016) and Hundie (2018), found evidence for EKC in some Sub-Saharan African countries but emphasized regional and sectoral disparities. Overall, the developing country literature suggests that the EKC may manifest under specific structural, institutional, and policy frameworks but is not universally applicable.

Beyond economic growth, empirical studies increasingly examine the EKC through the lens of financial development, which serves as both a driver of growth and an enabler of cleaner technology investments. In developed countries, results vary. Joe-Ming et al. (2015) found that financial development negatively impacted CO₂ emissions in eight OECD countries, while Ayeche et al. (2016) confirmed the EKC but found no direct causality between finance and emissions. Shahbaz et al. (2018) reported that financial development mitigated emissions in France, consistent with the pollution haven hypothesis. Similarly, Majeed and Mazhar (2019) demonstrated that private sector credit significantly reduced ecological footprints globally, although GDP and FDI increased them. However, studies such as Shahbaz et al. (2020) in the UAE and Ibrahim and Vo (2021) in 27 industrialized countries reveal nonlinear patterns—

U-shaped, N-shaped, or even W-shaped—highlighting the need for country-specific analysis. In developing countries, empirical outcomes are equally complex. Omri et al. (2015) validated the EKC in MENA countries but found finance-induced environmental degradation. Mesagan and Nwanchukwu (2018) and Musa et al. (2021) found bidirectional causality between finance and emissions in Nigeria, though the long-run impact was generally negative. Other studies, such as Zaidi et al. (2019) and Nyarkoa and Kaya (2021), supported the EKC while cautioning against generalizations, as the functional form of the EKC appeared to vary by country and context.

3. Methodology

This study employs a longitudinal panel data research design to capture the dynamic interactions among variables across both temporal and spatial dimensions. Panel data allows for the observation of multiple entities (countries) over time, thereby accounting for unobservable heterogeneity, controlling for omitted variables, and improving the efficiency of econometric estimates (Baltagi, 2005). The design is particularly suitable for investigating causality and long-run equilibrium relationships between financial development, economic growth, and environmental degradation.

The population for this study includes all 48 countries in the Sub-Saharan African region, as defined by the World Bank (2021). However, due to limitations in data availability and the requirement for consistency in the sample, a purposive sample of seven countries—Côte d'Ivoire, Ghana, Kenya, Mauritius, Namibia, Nigeria, and South Africa—was selected. These countries were chosen based on three primary criteria: (i) completeness of data from 1993 to 2021; (ii) their relatively advanced financial systems and dynamic economies; and (iii) regional representation across West, East, Southern, and Central Africa.

Secondary data are sourced primarily from the World Bank's World Development Indicators (WDI, 2021) and the Global Footprint Network (2021). These databases offer high-frequency, standardized macroeconomic and environmental statistics across countries. The panel data covers the period 1993 to 2021 and include variables on environmental degradation (carbon dioxide emissions and ecological footprint), financial development indicators, GDP per capita, energy consumption, foreign direct investment, urbanisation, and secondary school enrolment rates.

3.1 Model Specification

To test the EKC hypothesis in the selected SSA countries, the study adopts and modifies the models by Jiang and Ma (2019) and Dasuki and Olubusoye (2020). The dependent variables include carbon dioxide emissions per capita (CO₂) and ecological footprint per capita (EFP), both serving as proxies for environmental degradation. The main independent variables include financial development indicators—credit to the private sector (CPS), liquid liabilities ratio (LLR), market capitalization (MKC), stock market turnover ratio (SMT), interest rate spread (IRS), and stock market total value traded (STVT)—and economic growth, measured by GDP per capita (GDPPC).

In addition, the study introduces control variables: energy consumption (ENC), urbanisation (URB), foreign direct investment (FDI), and secondary school enrolment rate (SER). These are included to capture the broader socio-economic and policy environment affecting environmental outcomes.

Essentially, to examine the Environmental Kuznets Curve (EKC) hypothesis, the study applies the Autoregressive Distributed Lag (ARDL) modelling technique for country-specific analysis. The ARDL model is well-suited for this investigation because it accommodates variables that are stationary at levels (I(0)) or first difference (I(1)) and avoids the issue of pre-testing bias associated with other cointegration techniques (Pesaran, Shin & Smith, 2001).

The EKC hypothesis proposes an inverted U-shaped relationship between income (proxied by GDP per capita) and environmental degradation (proxied by CO₂ emissions or ecological footprint). This implies that the sign of the coefficient on income should be positive in the short run and negative on its squared term in the long run, or that long-run elasticity is smaller than short-run elasticity (Narayan & Narayan, 2010).

General Form of the ARDL Model

Let ED_{it} represent the measure of environmental degradation (either carbon emissions or ecological footprint), and GDPPC_{it} represent real GDP per capita. The unrestricted error correction model (UECM) form of ARDL used in this study is specified as follows for each country i:

Where:

$$\Delta \ln ED_{it} = \alpha_0 + \sum_{j=1}^p \alpha_j \Delta \ln ED_{i,t-j} + \sum_{j=1}^q \alpha_j \Delta \ln GDPPC_{i,t-j} + \sum_{j=1}^r \alpha_j \Delta (\ln GDPPC_{i,t-j})^2 + \theta_1 \ln ED_{i,t-1} + \theta_2 \ln GDPPC_{i,t-1} + \theta_3 (\ln GDPPC_{i,t-1})^2 + \varepsilon_{it}$$

Δ denotes the first difference operator,

α_0 is the constant term,

$\ln ED_{it}$ is the natural log of environmental degradation,

$\ln GDPPC_{it}$ is the natural log of GDP per capita,
 $(\ln GDPPC_{it})^2$ is the squared income term to capture nonlinearity,
 ε_{it} is the error term,
 $\theta_1, \theta_2, \theta_3$ represent the long-run relationships,

$\alpha_1^j, \alpha_2^j, \alpha_3^j$ capture the short-run dynamics.
 This model allows for asymmetric short- and long-run relationships between GDP per capita and environmental degradation.

Inclusion of Control Variables

To control for other determinants of environmental degradation, we augment the ARDL model by including energy consumption (ENC), urbanisation (URB), foreign direct investment (FDI), and education (SER) as control variables:

$$\Delta \ln ED_{it} = \alpha_0 + \sum_{j=1}^p \alpha_1^j \Delta \ln ED_{it-j} + \sum_{j=0}^q \alpha_2^j \Delta \ln GDPPC_{it-j} + \sum_{j=0}^r \alpha_3^j \Delta (\ln GDPPC_{it-j})^2 + \sum_{j=0}^s \alpha_4^j \Delta \ln ENC_{it-j} + \sum_{j=0}^u \alpha_5^j \Delta \ln URB_{it-j} + \sum_{j=0}^v \alpha_6^j \Delta \ln FDI_{it-j} + \sum_{j=0}^w \alpha_7^j \Delta \ln SER_{it-j} + \theta_1 \ln ED_{it-1} + \theta_2 \ln GDPPC_{it-1} + \theta_3 (\ln GDPPC_{it-1})^2 + \theta_4 \ln ENC_{it-1} + \theta_5 \ln URB_{it-1} + \theta_6 \ln FDI_{it-1} + \theta_7 \ln SER_{it-1} + \varepsilon_{it}$$

Where:

$\theta_1, \dots, \theta_7$ capture the long-run effects, and
 $\alpha_1^j, \dots, \alpha_7^j$ represent short-run effects for each variable.

Error Correction Representation (ECM)

The error correction model derived from the above ARDL equation is given by:

$$\Delta \ln ED_{it} = \sum_{j=1}^p \delta_j \Delta Z_{it-j} + \lambda ECM_{it-1} + \varepsilon_{it}$$

Where:

Z is a vector of the explanatory variables (GDPPC, GDPPC², ENC, URB, FDI, SER),
 ECM_{it-1} is the lagged error correction term derived from the long-run cointegrating relationship,
 λ is the speed of adjustment coefficient expected to be negative and statistically significant,
 A significant λ confirms the existence of a long-run equilibrium relationship.

EKC Validation Criteria in ARDL

The EKC hypothesis is validated in the ARDL framework based on two criteria:

Coefficient Significance and Signs:

$\theta_2 > 0$ (GDPPC increases emissions),
 $\theta_3 < 0$ (Squared GDPPC reduces emissions),

Together, this indicates an inverted U-shaped curve.

Narayan and Narayan (2010) Income Elasticity Rule:

If short-run elasticity of GDP is positive and significant, but long-run elasticity is negative and significant, the EKC hypothesis holds.

3.2 Measurement of Variables

Variable	Type	Measurement	Expected Sign	Sources
CO ₂ Emissions (CO ₂)	Dependent	Metric tons per capita	-	Alabi et al. (2021)
Ecological Footprint (EFP)	Dependent	Global hectares per capita	-	Khuky (2021)
GDP per capita (GDPPC)	Independent	GDP divided by total population	+ (short), - (long)	Hasan et al. (2021)
Energy Consumption (ENC)	Control	Per capita energy use	+	Longe et al. (2020)
Urbanization (URB)	Control	Urban population as % of total population	+	Kwakwa & Alhassan (2020)
Foreign Direct Investment (FDI)	Control	Net inflows as % of GDP	+	Isiksal et al. (2019)
Secondary School Enrolment (SER)	Control	% of relevant age group enrolled in secondary education	+	Kwakwa & Alhassan (2020)

Author's Compilation (2025)

3.3 Estimation Techniques

To capture both long-run and short-run dynamics, this study employs the Pooled Mean Group (PMG) and Mean Group (MG) estimators within the Autoregressive Distributed Lag (ARDL) framework as developed by Pesaran,

Shin, and Smith (1999). These techniques are suitable for heterogeneous panels with mixed order of integration (I(0) and I(1)).

Unit root tests will first be conducted using the Im, Pesaran and Shin (2003) (IPS) procedure to determine the stationarity properties of the variables. Once non-stationarity is established, the Pedroni (1999, 2001) panel cointegration test will be applied to examine the presence of a long-run equilibrium relationship among the variables.

Granger causality tests will also be performed within a panel vector error correction framework to identify causal directions between financial development, economic growth, and environmental degradation. This will help assess whether the relationships are uni-directional or bi-directional (feedback). The specific form of the Granger test used follows the model:

$$Y_{it} = \beta_0 + \sum_{k=1}^m \beta_k Y_{it-k} + \sum_{l=1}^n \alpha_l X_{it-l} + u_t$$

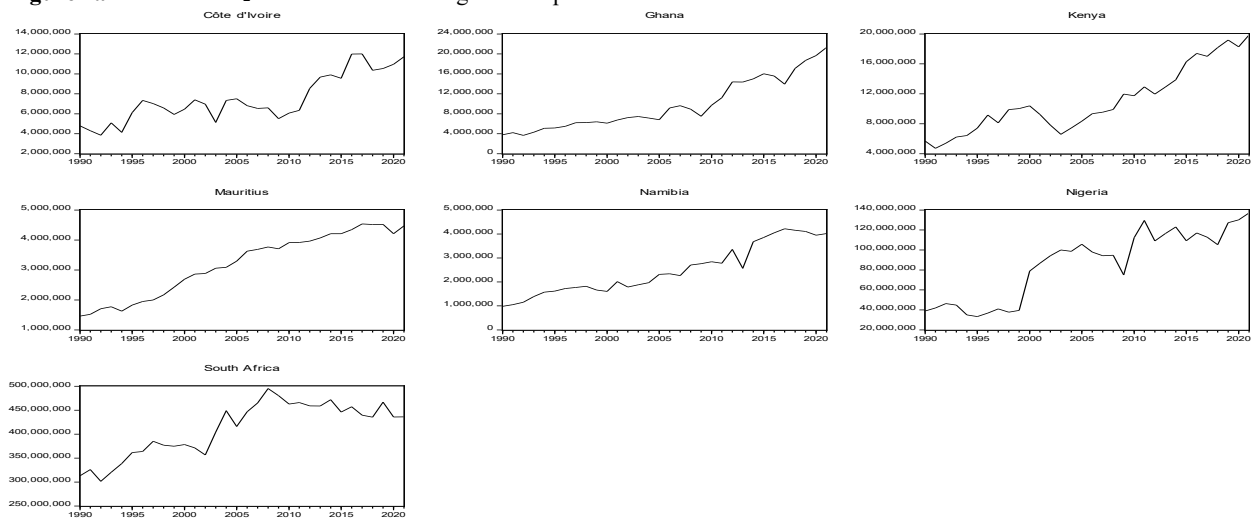
$$X_{it} = \gamma_0 + \sum_{k=1}^m \delta_k X_{it-k} + \sum_{l=1}^n \phi_l Y_{it-l} + v_t$$

Where Y denotes environmental indicators (CO2 or EFP), and X refers to financial development or GDP per capita.

4. Results and Discussions

This section presents the empirical results of the study using several statistical tools, including trend analysis descriptive statistics, unit root tests, correlation analysis, cointegration tests, the ARDL model for long- and short-run estimates to test the existence of the Environmental Kuznets Curve (EKC), and Granger causality tests.

Figure 1a Trends in CO₂ Emissions and Ecological Footprint



Source: Author's computation (2025) with the aid of E-view 9.0 econometric software

Figure 1b Trends in Ecological Footprint



Source: Author's computation (2025) with the aid of E-view 9.0 econometric software

Figure 1 shows a steady rise in CO₂ emissions across the Sub-Saharan African countries studied, indicating a growing—though comparatively modest—contribution to global environmental degradation. For example, emissions in Côte d'Ivoire increased from 4 million tonnes in 1990 to over 10 million in 2022, while Nigeria's emissions rose from 40 million to 120 million tonnes. Figure 2 highlights ecological footprint per capita, disaggregated into cropland (EFPC) and built-up land (EFPI), with EFPC more prominent in Côte d'Ivoire, Namibia, and South Africa, and EFPI higher in Ghana, Nigeria, and Mauritius. Except for Mauritius, where a decline is noted, most countries exhibit flat or increasing ecological footprints, suggesting rising environmental pressure across the region.

Table 1: Descriptive Statistics for Panel Data

Variable	Mean	Max.	Min.	Std. Dev.	Skew.	Kurt.	J-B	Prob.
GCO2	4.51	99.11	-26.23	13.39	2.12	14.71	1402.96	0.00
EFPC	0.73	1.24	0.18	0.25	-0.28	2.68	3.83	0.15
EFPI	2.20	16.08	0.11	4.00	2.35	7.05	348.42	0.00
FDI	2.23	10.66	-1.42	2.25	1.58	5.19	133.22	0.00
GGDPPC	1.59	12.28	-14.60	3.38	-0.75	5.81	91.92	0.00
URB	42.46	67.85	17.04	11.83	-0.19	2.64	2.47	0.29
SER	2.05	4.01	1.24	0.42	0.65	5.84	88.52	0.00
GENC	2.83	187.03	-31.43	18.01	6.48	62.24	33248.26	0.00

Source: Author's computation (2025) with the aid of E-view 9.0 econometric software

The descriptive statistics in Table 1 reveal substantial variability in the panel data, particularly for greenhouse gas emissions (GCO2), ecological footprint index (EFPI), and energy consumption (GENC). GCO2 has a high standard deviation (13.39) and a maximum value of 99.11, indicating wide disparities in emissions levels across countries and time, with strong right-skewness (2.12) and leptokurtosis (14.71), as confirmed by a significant Jarque-Bera (J-B) test ($p = 0.00$). EFPC is relatively stable, with a low mean (0.73) and standard deviation (0.25), and its distribution is near normal (J-B $p = 0.15$). EFPI, FDI, and GGDPPC all display significant skewness and kurtosis, suggesting non-normality in their distributions. The extreme kurtosis in GENC (62.24) and the highest J-B statistic (33,248.26) highlight the presence of outliers or volatility in energy use, which could significantly

influence regression estimates. Urbanization (URB) appears more normally distributed (J-B $p = 0.29$), indicating a relatively consistent demographic trend across countries.

Table 2: Descriptive Statistics for Individual Countries

COUNTRY	GCO2	EFPC	EFPI
Côte d'Ivoire	4.32	0.79	0.56
Ghana	6.39	0.84	1.04
Kenya	4.72	0.62	0.63
Mauritius	3.79	1.06	11.66
Namibia	5.30	0.28	0.13
Nigeria	5.85	0.64	0.75
South Africa	1.21	0.85	0.70

Source: Author's computation (2025) with the aid of E-view 9.0 econometric software

Table 2 presents country-specific averages for carbon dioxide emissions (GCO2), ecological footprint per capita (EFPC), and ecological footprint index (EFPI) across seven Sub-Saharan African countries. Ghana and Nigeria exhibit the highest average CO₂ emissions at 6.39 and 5.85 metric tons per capita, respectively, indicating more intensive carbon outputs, possibly due to larger industrial bases and energy use. Conversely, South Africa, despite its advanced economy, reports the lowest average GCO₂ (1.21), which may reflect better energy efficiency or structural shifts toward less emission-intensive sectors. In terms of EFPC, Mauritius leads (1.06), reflecting a higher per capita demand on biological resources, while Namibia records the lowest (0.28), suggesting lower environmental pressure per person. Notably, Mauritius also displays a substantially higher EFPI (11.66), indicating a concentrated environmental footprint likely associated with its dense urban infrastructure and tourism-driven land use.

Table 3: Correlation Matrix

Variable	CO2	EFPC	EFPI	GDPPC	FDI	ENC	URB	SER
CO2	1							
EFPC	0.21 (0.00)	1						
EFPI	-0.19 (0.00)	0.61 (0.00)	1					
GDPPC	0.35 0.00	0.32 0.00	0.54 0.00	1				
FDI	-0.16 (0.02)	-0.11 0.12	-0.07 (0.30)	0.09 (0.19)	1			
ENC	0.82 0.00	0.19 0.00	0.09 (0.20)	0.62 0.00	0.00 (0.94)	1		
URB	0.63 0.00	0.41 0.00	0.02 (0.73)	0.39 0.00	0.13 0.06	0.61 (0.00)	1	
SER	0.35 (0.00)	0.27 (0.00)	0.27 (0.00)	0.60 (0.00)	0.24 (0.00)	0.54 (0.00)	0.37 (0.00)	1

Source: Author's computation (2025) with the aid of E-view 9.0 econometric software

The correlation matrix in Table 3 reveals significant relationships between key variables of financial development, economic activity, and environmental degradation. CO₂ emissions (CO2) show a strong positive correlation with energy consumption (ENC, $r = 0.82$, $p < 0.01$) and urbanization (URB, $r = 0.63$, $p < 0.01$), indicating that rising energy use and urban expansion are major contributors to environmental degradation in Sub-Saharan Africa. A moderate positive correlation also exists between CO₂ and GDP per capita ($r = 0.35$, $p < 0.01$), suggesting that economic growth may exacerbate emissions. Conversely, CO₂ is weakly and negatively associated with ecological footprint index (EFPI, $r = -0.19$, $p < 0.01$), reflecting possible divergences in how carbon and broader environmental pressures evolve. Notably, foreign direct investment (FDI) is negatively correlated with CO₂ ($r = -0.16$, $p = 0.02$), potentially indicating that FDI in the region is not predominantly directed toward polluting

sectors, or that it may support cleaner technologies. Secondary school enrollment (SER) is positively correlated with most variables, including CO₂ and GDPPC, implying that human capital development co-evolves with economic and environmental indicators.

Table 4a: Panel Data Unit Root Tests Results in Levels

Variables	<i>Common unit process</i>		<i>individual unit root process</i>	
	LLC	IPS	ADF	PP-Fisher
LCO2	-2.63**	0.37	10.31	9.72
EFPC	0.21	-0.52	17.31	33.82*
EFPI	2.06**	-0.60	28.41*	43.53*
ENC	-0.93	1.39	8.11	6.53
GDPPC	0.17	2.92	4.03	3.66
FDI	-2.25**	-3.56**	36.96**	52.69**
URB	0.07	3.60	4.61	27.41
SER	-1.80	5.72	4.87	0.64

Source: Estimated by the Author. *Note:* ** and * indicate significant at 1% and 5 % levels respectively; IPS = Im, Pesaran & Shin; LLC = Levin, Lin & Chu

Table 4b: Panel Data Unit Root Tests Results in First Differences

Variables	<i>Common unit process</i>		<i>individual unit root process</i>	
	LLC	IPS	ADF	PP-Fisher
LCO2	-7.60**	-8.61**	93.85**	176.2**
EFPC	-10.51**	-12.77**	132.8**	186.4**
EFPI	-7.13**	-13.28**	138.8**	209.4**
ENC	-6.67**	-6.79*	72.29**	165.7**
GDPPC	-4.00*	-3.28*	34.14**	69.85**
FDI	-7.49**	-10.75**	120.0**	189.4**
SER	4.03*	1.63	7.618	45.62**
URB	3.86*	3.56*	5.673	6.83

Source: Estimated by the Author. *Note:* ** and * indicate significant at 1% and 5 % levels respectively; IPS = Im, Pesaran & Shin; LLC = Levin, Lin & Chu

The panel unit root test results in Tables 4a and 4b indicate that most variables are non-stationary at levels but become stationary after first differencing, justifying the use of an ARDL modeling framework suitable for mixed integration orders. At levels, only CO₂ emissions (LCO2), foreign direct investment (FDI), and partially market indicators (e.g., EFPI in the ADF and PP tests) show signs of stationarity, while others such as GDP per capita (GDPPC), ecological footprint per capita (EFPC), and urbanization (URB) are non-stationary. However, in first differences, all variables—including EFPC, EFPI, GDPPC, FDI, and energy consumption (ENC)—are stationary at 1% significance across multiple testing approaches (LLC, IPS, ADF, and PP-Fisher), except for urbanization and school enrollment (URB and SER), which display mixed results. These outcomes validate the appropriateness of ARDL bounds testing and PMG estimation in analyzing long-run and short-run relationships among variables with differing integration properties.

Table 5: Cross-section Dependence Test Results

Equation series tested	Pesaran CD	P-value	Abs corr
CO ₂	0.635	0.516	0.144
EFC	1.123	0.239	0.195
EFPI	-0.692	0.488	0.170

Source: Author’s computations (2025)

The results from the Pesaran cross-section dependence test in Table 5 show no significant cross-sectional dependence for CO₂ emissions, ecological footprint per capita (EFC), or ecological footprint index (EFPI), as indicated by p-values well above 0.05, suggesting that the panel units are sufficiently independent for reliable panel estimation.

Table 6: Results of Bounds Test of Cointegration

Country	F-statistic	I(0)	I(1)
Côte d'Ivoire	54.86	2.04	2.08
Ghana	3.72	2.04	2.08
Kenya	82.93	2.04	2.08
Mauritius	11.34	2.04	2.08
Namibia	13.44	2.04	2.08
Nigeria	5.12	2.04	2.08
South Africa	2.12	2.04	2.08

Source: Author's computation (2025)

The bounds test results in Table 6 indicate cointegration between financial development and environmental degradation in all countries except South Africa, as their F-statistics exceed the upper critical bound ($I(1) = 2.08$), confirming long-run relationships in Côte d'Ivoire, Ghana, Kenya, Mauritius, Namibia, and Nigeria.

Table 7: Short Run PMG Estimates

Variable	LCO ₂			EFPC			EFPI		
	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.
Constant	3.172	2.934	0.00	0.030	0.140	0.89	0.510	0.423	0.67
$\Delta LGDPPC$	0.135	0.247	0.81	1.490	2.342	0.02	8.579	1.285	0.20
$\Delta LGDPPC_{t-1}$	0.237	0.663	0.51	0.698	1.537	0.13	-5.896	-0.902	0.37
$\Delta LENC$	0.330	1.236	0.22	-0.270	-1.156	0.25	-0.624	-1.213	0.23
$\Delta LENC_{t-1}$	0.277	1.491	0.14	-0.279	-1.068	0.29	0.152	0.164	0.87
ΔURB	3.655	1.501	0.14	0.678	1.241	0.22	-6.678	-1.009	0.32
ΔURB_{t-1}	-3.518	-1.450	0.15	-1.508	-2.048	0.04	-0.769	-0.729	0.47
ΔFDI	0.007	0.549	0.58	-0.011	-1.479	0.14	-0.039	-1.376	0.17
ΔFDI_{t-1}	0.000	0.020	0.98	-0.004	-0.925	0.36	0.027	0.774	0.44
ΔSER	3.688	1.238	0.22	3.774	0.998	0.32	27.358	1.100	0.27
ΔSER_{t-1}	4.828	0.990	0.33	-1.148	-0.299	0.77	-48.494	-1.109	0.27
ECM_{t-1}	-0.511	-2.882	0.01	-0.659	-4.042	0.00	-0.010	-0.153	0.88
S.E. of reg.	0.088			0.000			-0.047		
Mean dep. Var.	0.038			0.049			0.401		

Source: Author's computation (2025)

The short-run Panel Mean Group (PMG) estimates presented in Table 7 reveal mixed and largely insignificant effects of key explanatory variables on environmental degradation indicators across selected Sub-Saharan African countries. Specifically, changes in GDP per capita ($\Delta LGDPPC$) have no significant short-term effect on CO₂ emissions (LCO₂), but significantly increase ecological footprint per capita (EFPC) ($p = 0.02$), suggesting that income growth in the short term may intensify resource use and environmental pressure—consistent with the early-stage dynamics of the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995; Narayan & Narayan, 2010). The insignificant impact of GDP per capita on the ecological footprint index (EFPI) and CO₂ suggests delayed or context-specific responses, possibly reflecting lags in policy or technological adaptation. Energy consumption ($\Delta LENC$) and urbanization (ΔURB) also display no statistically significant immediate effect, though lagged urbanization negatively and significantly impacts EFPC ($p = 0.04$), implying a possible adjustment effect where prior urban expansion moderates environmental pressure over time—a finding that aligns with the structural transition perspectives in EKC theory (UNCTAD, 2012).

Furthermore, the error correction terms (ECMt-1) are significantly negative for both CO₂ (-0.511 , $p = 0.01$) and EFPC (-0.659 , $p = 0.00$), confirming the existence of stable long-run equilibria and the system's ability to correct deviations from long-term environmental trends. The insignificance of ECM in the EFPI model indicates that broader environmental stresses captured by the index are less responsive to short-run shocks, reinforcing the idea that structural and policy reforms are required to address cumulative ecological pressures (Arrow et al., 1995). Overall, these results reflect the complexity of environmental dynamics in developing contexts, underscoring the limited efficacy of short-term economic growth in improving environmental outcomes and supporting the need for comprehensive, long-run sustainability strategies in line with revised EKC interpretations (Dasgupta et al., 2002; Majeed & Mazhar, 2019).

Table 8a: Long Run PMG Estimates

Variable	LCO2			EFPC			EFPI		
	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.
<i>LGDPCC</i>	0.819	4.330	0.00	0.045	0.563	0.58	8.023	2.444	0.02
<i>LENC</i>	0.178	3.025	0.00	0.080	2.244	0.03	-4.659	-2.661	0.01
<i>URB</i>	0.076	4.063	0.00	0.028	8.209	0.00	0.142	1.595	0.11
<i>FDI</i>	0.004	0.389	0.70	0.003	2.220	0.03	-0.235	-2.759	0.01
<i>SER</i>	-0.417	-0.716	0.48	-0.687	-8.770	0.00	-10.572	-2.372	0.02

Source: Author's computation (2025)

The long-run PMG estimates in Table 8a provide robust empirical support for the Environmental Kuznets Curve (EKC) hypothesis, particularly in relation to CO₂ emissions and the ecological footprint index (EFPI). Specifically, GDP per capita (LGDPCC) exerts a strong and statistically significant positive effect on CO₂ emissions (0.819, p = 0.00) and EFPI (8.023, p = 0.02), indicating that as income increases, environmental degradation also intensifies in the long run—consistent with the initial upward trajectory of the EKC. However, its non-significant effect on the ecological footprint per capita (EFPC) suggests that income-driven environmental impacts may not uniformly translate across all dimensions of ecological stress. This asymmetry aligns with previous findings that CO₂ emissions and broader ecological indicators may respond differently to economic growth (Friedl & Getzner, 2003; Majeed & Mazhar, 2019). Moreover, energy consumption (LENC) significantly increases CO₂ and EFPC, but notably reduces EFPI, reflecting the differentiated environmental effects of energy use depending on the specific metric assessed—a dynamic also observed in studies such as Saboori et al. (2012) and Tiwari et al. (2013).

Table 8b: Individual Country Long Run Results

Variable	Cote d'Ivoire		Ghana		Kenya		Mauritius		Namibia		Nigeria		South Africa	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
<i>LGDPCC</i>	-2.113	0.106	4.138	0.136	2.988	0.081	-5.737	0.005	-1.151	0.138	-0.611	0.037	-1.563	0.179
<i>LENC</i>	0.798	0.323	-0.747	0.535	-3.227	0.010	0.612	0.027	-0.050	0.744	1.030	0.001	1.719	0.036
<i>FDI</i>	0.348	0.053	-0.171	0.006	0.081	0.031	0.001	0.933	-0.073	0.043	0.006	0.735	0.010	0.282
<i>URB</i>	0.335	0.258	0.850	0.001	2.143	0.016	-5.698	0.001	-0.032	0.395	-0.035	0.509	0.562	0.175
<i>SER</i>	0.717	0.937	-26.90	0.002	-15.003	0.027	-16.42	0.013	4.381	0.092	1.776	0.275	-0.071	0.565
<i>Constant</i>	16.869	0.069	1.048	0.893	17.428	0.155	341.2	0.007	17.095	0.047	16.09	0.000	-0.252	0.200

Source: Author's computation (2025)

The long-run country-specific estimates in Table 8b reveal significant heterogeneity in the relationship between economic growth and environmental degradation across the selected Sub-Saharan African countries, highlighting the context-dependent applicability of the Environmental Kuznets Curve (EKC) hypothesis. For instance, Kenya and Mauritius demonstrate statistically significant results for GDP per capita (LGDPCC), with Kenya showing a positive and near-significant coefficient (2.988, p = 0.081), suggesting early-stage growth-induced environmental pressure, while Mauritius exhibits a significant negative coefficient (-5.737, p = 0.005), aligning with the EKC's post-turning point decline in degradation. Conversely, countries such as Nigeria (-0.611, p = 0.037) show modest but significant reductions in environmental degradation with rising income, reinforcing the idea that the EKC may be observable under certain institutional and developmental conditions (Narayan & Narayan, 2010; Shahbaz et al., 2012). Energy consumption (LENC) is a critical driver of environmental outcomes, with mixed signs across countries—significantly increasing degradation in Nigeria and South Africa, but reducing it in Kenya (-3.227, p = 0.010), suggesting divergent energy efficiency levels or renewable energy adoption.

Table 9: Results for Testing Kuznets Hypothesis

Variable	LCO2			EFPC			EFPI		
	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.	Coeff.	t-ratio	prob.
<i>Long Run Equation</i>									
<i>LGDPCC</i>	254.7	8.540	0.00	24.08	2.995	0.00	-303.6	-10.266	0.00
<i>LGDPCC2</i>	32.06	8.489	0.00	2.957	2.880	0.00	39.31	10.338	0.00
<i>LGDPCC3</i>	-1.337	-8.434	0.00	-0.121	-2.783	0.01	-1.690	-10.436	0.00

<i>LENC</i>	0.921	7.119	0.00	-0.026	-1.259	0.21	-0.022	-0.365	0.72
<i>URB</i>	0.019	2.810	0.01	-0.005	-1.304	0.20	0.058	4.737	0.00
<i>FDI</i>	-0.014	-1.670	0.10	0.006	3.623	0.00	0.039	9.051	0.00
<i>SER</i>	0.105	1.477	0.14	0.167	1.845	0.07	-0.038	-0.196	0.84
<i>Short Run Equation</i>									
<i>ECM_{t-1}</i>	-0.517	-2.864	0.00	-0.887	-5.399	0.00	-0.560	-2.739	0.01
<i>ALGDPPC</i>	1572.2	2.178	0.03	1968.1	0.838	0.40	2380.5	0.851	0.40
<i>ALGDPPC_{t-1}</i>	--	--	--	-1385.2	-1.508	0.13	806.6	0.925	0.36
<i>ALGDPPC²</i>	-206.3	-2.159	0.03	-227.9	-0.830	0.41	-278.8	-0.844	0.40
<i>ALGDPPC²_{t-1}</i>	--	--	--	169.1	1.588	0.12	-86.74	-0.818	0.42
<i>ALGDPPC³</i>	9.043	2.137	0.03	8.816	0.825	0.41	10.996	0.846	0.40
<i>ALGDPPC³_{t-1}</i>	--	--	--	-6.903	-1.679	0.10	3.076	0.709	0.48
<i>Mean dep. var</i>	0.037								
<i>S.E. of reg.</i>	0.096								

Source: Author's computation (2025)

The results from Table 9 offer strong empirical support for a non-linear, cubic Environmental Kuznets Curve (EKC) relationship between economic growth (proxied by log of GDP per capita and its squared and cubic terms) and environmental degradation across all three indicators—CO₂ emissions (LCO₂), ecological footprint per capita (EFPC), and ecological footprint index (EFPI). Specifically, the signs and statistical significance of the coefficients for LGDPPC (positive), LGDPPC² (positive), and LGDPPC³ (negative) confirm the existence of an N-shaped EKC, implying that environmental degradation initially increases with income, declines after reaching a certain threshold, but may rise again at higher levels of income (Moomaw & Unruh, 1997; Carvalho & Almeida, 2010). This supports the generalized EKC model, particularly relevant to long-term dynamics in developing regions like Sub-Saharan Africa where late-stage growth may reignite environmental stress without sustained green reforms.

Moreover, the error correction terms (ECMt-1) are negative and significant for all models, confirming the presence of stable long-run relationships and suggesting that any short-term disequilibrium in environmental degradation adjusts back toward equilibrium over time. The strong positive influence of urbanization and FDI on EFPI and EFPC, respectively, aligns with findings by Saboori et al. (2012) and Omri et al. (2015), which suggest that foreign investment and urban expansion can intensify ecological pressures if not managed with environmental safeguards. Additionally, the weak short-run significance of the GDP-related terms indicates that structural changes in environmental outcomes materialize primarily in the long run. These findings reinforce the critique of the simplistic EKC model and call for dynamic, policy-sensitive interpretations of the income–environment nexus (Arrow et al., 1995; Neumayer, 2002).

Table 10: Causality Test Result

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LCO ₂ does not homogeneously cause LGDPPC	3.427	1.398	0.162
LGDPPC does not homogeneously cause LCO ₂	6.513	4.840	0.000
EFPC does not homogeneously cause LGDPPC	2.740	0.631	0.528
LGDPPC does not homogeneously cause EFPC	8.331	6.868	0.000
EFPI does not homogeneously cause LGDPPC	3.061	0.990	0.322
LGDPPC does not homogeneously cause EFPI	12.161	11.140	0.000

Source: Author's computation (2025)

The causality test results in Table 10 provide strong empirical evidence of unidirectional causality running from economic growth (proxied by log of GDP per capita) to all three measures of environmental degradation CO₂ emissions (LCO₂), ecological footprint per capita (EFPC), and ecological footprint index

(EFPI) at a 1% significance level, confirming the proposition of income-driven environmental pressure articulated in the Environmental Kuznets Curve (EKC) literature (Grossman & Krueger, 1993; Shahbaz et al., 2012). Conversely, there is no statistically significant causality from any of the

environmental indicators to economic growth, which aligns with the notion that environmental degradation is largely a consequence, not a cause, of growth processes, especially in developing regions such as Sub-Saharan Africa (Narayan & Narayan, 2010; Kwakwa & Adu, 2016). These findings reinforce the imperative for sustainable development policies that integrate environmental safeguards early in the growth trajectory to mitigate the long-run ecological consequences of economic expansion.

5. Conclusion and Recommendations

This study provides robust empirical evidence supporting a non-linear Environmental Kuznets Curve (EKC) relationship between economic growth and environmental degradation across selected Sub-Saharan African (SSA) countries. The cubic functional form of the EKC observed for all three indicators CO₂ emissions, ecological footprint per capita (EFPC), and ecological footprint index (EFPI) validates the presence of an N-shaped dynamic, wherein environmental degradation rises with income at early stages, declines after a threshold, and potentially rises again at higher income levels. The long-run results reveal that GDP per capita significantly increases CO₂ and EFPI, while energy consumption and foreign direct investment (FDI) show heterogeneous effects depending on the environmental indicator. The panel error correction model further confirms long-term equilibrium adjustment in environmental outcomes. Importantly, causality tests affirm that GDP per capita Granger-causes all three environmental degradation indicators, reinforcing the centrality of income growth in shaping ecological trajectories in SSA.

Given the confirmed N-shaped EKC pattern, policymakers in SSA should avoid over-reliance on economic growth alone as a means of environmental improvement. The potential for renewed environmental degradation at higher income levels underscores the need for proactive regulatory frameworks and investments in green infrastructure to ensure that development transitions into a sustainable trajectory. Governments should enforce environmental regulations, incentivize renewable energy adoption, and establish pollution taxes or emissions trading systems to decouple income growth from ecological stress. Moreover, given the differentiated impacts of FDI across environmental indicators, investment policies must prioritize sectors with low environmental externalities and integrate

sustainability criteria in foreign investment approvals.

Education and technological innovation emerge as critical levers for long-run ecological resilience. Expanding access to quality secondary and tertiary education especially in science, technology, engineering, and mathematics (STEM) can foster human capital capable of developing and applying eco-efficient technologies. Urbanization, while a potential environmental stressor, can be managed sustainably through integrated urban planning, investment in public transport, green spaces, and energy-efficient infrastructure. Energy policy reform is also essential: governments should implement energy diversification strategies that reduce reliance on fossil fuels and scale up solar, wind, and hydroelectric capacity, as seen in Kenya's relative energy efficiency gains. Collectively, these targeted strategies will allow SSA economies to navigate the EKC path toward sustained environmental and economic well-being.

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