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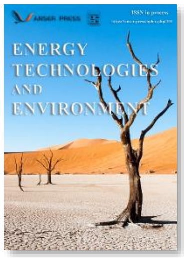

Renewable Energy and Ecological Sustainability in Africa: Does Foreign Debt and Financial Globalisation Matter?

Magaji Yakubu [a], Samson Aladejare [a, *]

[a] *Department of Economics, Federal University Wukari, Nigeria*

ABSTRACT

Since the last decade, ecological preservation has become a critically debated topic in developing and developed nations. Hence, to ensure environmental sustainability, countries and international bodies have canvassed for measures that support severe restrictions to protect the Earth's biodiversity. This study's objectives were two-fold: the sole effect of renewable energy on ecological sustainability and second, identify the impacts of external debt and financial globalisation in the renewable energy-ecological sustainability nexus, both within the Environmental Kuznet Curve (EKC) framework for 44 African economies. Second-generation estimation techniques were employed and deduced inferences from the cross-sectional autoregressive distributed lag method used in the study. The study empirically demonstrated that renewable energy is insignificant for ecological sustainability without debt stock and financial globalisation. However, the inclusion of both variables revealed that while renewable energy and financial globalisation accelerated ecological sustainability, external debt worsened it in the short and long-term periods. Therefore, the study proposed amongst others that for the productive benefits of renewable energy use to human and environmental well-being, policymakers must execute clean energy portfolios by restricting brown energy use. This measure will require considering introducing a significant amount of carbon tax or emission permit and incentivising businesses to adopt green technologies.

KEYWORDS

Renewable energy; Environmental sustainability; External debt; Financial globalisation; Economic growth; Africa

* Corresponding author: Samson Aladejare
E-mail address: aladejare4reel2000@gmail.com

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1. Introduction

The unprecedented rise in global energy demand has been generating critical concerns in recent decades due to its intense contribution to the context of global warming (Aladejare, 2022a; Aladejare, 2023a; Akram et al., 2022). For instance, in 1980, the energy consumption level was 7.323 terawatt-hours, but it moved to 25.343 terawatt-hours in 2021 (IRENA, 2022). Similarly, the average global temperature in 2021 alone was about 1.11^{0}C, while the world temperature data from 2015 to 2021 consistently exceeded 1^{0}C, rising beyond the pre-industrial levels (Aladejare, 2022a). A pointer is that the preference for energy by households and businesses has been the primary source of greenhouse gas (GHG) emissions. 80% of today's fossil energy sources (oil, natural gas, and coal) are unsustainable but have powered economies for over 150 years (Ritchie et al., 2022). Thus, national governments and international organisations have continued to worry about managing the trend since nations can hardly develop without energy consumption. Energy is crucial in generating the needed activities that contribute to economic growth and development. Intuitively, economic activities in every country rely mainly on energy use, given its pivotal role in accelerating productivity, income generation, and employment. However, many extant studies concur that the environment responds positively or negatively to the economic growth-energy utilisation nexus (Usman et al., 2019; Sarkodie and Strezov, 2019; Usman et al., 2020; Iorember et al., 2020; Aladejare, 2023a). Thus, nations face the dilemma of reducing energy utilisation intensity and reaping negative economic growth and development; or continuing the prevalence of unsustainable energy and exacerbating environmental atrophy.

Since energy utilisation is one significant factor responsible for economic growth and development, a smooth transition from unsustainable to environmental-friendly sources is needed. Hence, renewable energy sources have attracted the desired attention of many economies due to their cost-effective merit and role in mitigating climate change. Global interest in renewable energy sources, including wind, nuclear, hydrogen, and solar, are conscientious and emission-free (Samour and Adebayo, 2022; Aladejare, 2023b,c). In 2018 for instance, improved cleaner energy adoption aided the decline in ecological pollution by thwarting 215 million tons (Mt) of emissions globally (Adedoyin et al., 2021; Sadiq et al., 2022). Hence, economies are scaling-up their share of renewable energy adoption to enlarge their carbon-free and cost-effective energy supply. Other benefits include downgrading dependence on volatile imported fossil energy, cutting adverse effects of fossil energies, and accelerating the transition to efficient and clean energy. For instance, despite the vast potential of solar energy, only 5% of this potential is exploited globally (Fotio et al., 2022). However, it is pertinent to note that renewable energy transition alone cannot deliver environmental sustainability as other critical factors must be considered in the process.

As identified in recent studies, one measure for slowing down the rate of GHG emissions is to scale up investment in green economy and infrastructure (Shahnazi and Shabani, 2021; Mehmood, 2021; Yu et al., 2022; Fotio et al., 2022). Therefore, deploying public borrowing for green economic and infrastructural development can be tagged as borrowing for sustainability. Since the mid-1990s, foreign indebtedness has soared, and advanced economies, followed by emerging countries, accounted for most of the significant growth in foreign debt (Akam et al., 2021; Ebi and Aladejare, 2022). Similarly, in recent times, developing countries have been accumulating external debt due to the substantial saving-investment gap in these countries (Sun and Liu, 2020; Aladejare, 2022c; Aladejare, 2023b,d). Nevertheless, external indebtedness is also critical in the campaign for environmental protection. In most energy-reliant nations, external debt contributes immensely to resource use (Sun and Liu, 2020). Also, investing foreign borrowing into heavy industry, real estate, and the construction sector can surge emissions and potentially trigger adverse ecological implications (Bese et al., 2022; Aladejare and Nyiputen, 2023).

Also, recent studies are beginning to stress the critical role of financial globalisation (FGB) in achieving environmental sustainability. For instance, countries may erect financial regulations and barriers on investment projects that will receive foreign collaboration and what regulations foreign investors will comply with while investing in foreign countries. Such enabling laws may hinder or promote the free flow of international funds and investment in ecologically sustainable projects. The last three decades have seen globalisation expand and result in financial development as an essential ingredient responsible for the economic progress of countries (Erdoğan et al., 2020; Kirikkaleli and Adebayo, 2021; Kihombo et al., 2022; Miao et al., 2022). Thus, African economies are urged to remove constrains to external financial portfolios and investment inflows due to the pressing need to tackle poverty and achieve rapid output growth. However, studies have shown that ecological sustainability does not always responds positively to foreign financial development. For instance, African economies' quest for external financial investment has made them vulnerable to all forms of foreign financial aid and investment that can be ecologically detrimental.

Therefore, this study's objectives are: first, determine the sole effect of renewable energy on ecological sustainability within the theoretical context of the environmental Kuznet curve (EKC). Second, given the EKC hypothesis, identify the impacts of external debt and FGB in the renewable energy-ecological sustainability nexus in Africa. This study dwelled on African countries for three principal grounds. First, the continent is a minor carbon emitter globally (Aladejare, 2022a; Aladejare and Nyiputen, 2023). However, Africa's emission growth rate has exceeded other regions, such as East and Central Europe (Fotio et al., 2022). It is not unlikely that the continent's GHG emissions could significantly outpace other regions in a few years due to the widespread usage of dirty energy across African countries (UN, 2021). For instance, Africa's energy demand grew from 91 to 163 terawatt-hours between 2010 and 2020, respectively; and is projected to reach 463 terawatt-hours by 2040 (IRENA, 2022). Second, globally, countries are fast upgrading to renewable energy sources to curtail GHG emissions, hence, the need to assess its ecological effect on the continent. Third, the post-2015 goal of the African Development Bank, among their development preferences, includes enhancing the quality of life, powering, and integrating Africa. By integration, the plan seeks to connect Africa through infrastructures and globalisation, which will aid in better access to broader markets. About 95% of renewable energy projects in the continent are funded through grants, while 3% and below 1% are with loans and private equity, respectively (Fotio et al., 2022). Given that grants are deployed for small-scale projects, the execution of energy projects on an enormous scale in highly impoverished economies such as Africa demands foreign financing through debt, foreign investments, development support, foreign organisations, or regional development Banks in public infrastructure accumulation.

There are three perspectives to which this study contributes to the literature. First, today's primary policy focus of most countries reflects sustainable development. Thus, this study extends the literature by considering the role of renewable energy in ecological sustainability towards climate change mitigation. Of particular interest is the pace of renewable energy adoption in African countries characterised by energy grid systems that are some of the least efficient in the world (Asongu et al., 2019; Aladejare, 2020; Asongu and Odhiambo, 2021). Second, a substantial rise in external debt and its effect has attracted much concern from the empirical literature. Most empirical studies have linked external debt to economic growth and development, macroeconomic policies, energy issues, etc. (IMF, 2019; Chien et al., 2022; Azolibe, 2022; Aladejare, 2023b,d). However, limited studies have assessed the effect of external debt on ecological sustainability in emerging and developing economies. Interestingly, most such studies have focussed on CO_2 (carbon dioxide) emissions to proxy environmental sustainability (Akam et al., 2021; Bese and Friday, 2022; Sadiq et al., 2022). Thus, scant literature relates foreign borrowing to the ecological footprint (EFP), a more comprehensive measure of environmental sustainability.

Third, extant FGB literature on Africa has often adopted indicators such as foreign direct investment, portfolio investment, and remittances (Asongu and De Moor, 2017; Asongu and Nnanna, 2020; van Treeck and Wacker, 2020; Holzl, 2021; Asongu and Nnanna, 2021). Consequently, this study leads by adopting the aggregate KOF FGB index for a comprehensive African analysis. Its adoption is because, aside from the poor state of inclusive development in Africa, factors such as climate change, ecological degradation, and exclusive growth are mainly linked to inadequate funding and poor financial development (Joshua and Alola, 2020; Asongu et al., 2020; Joshua et al., 2020, Nathaniel and Bekun, 2021). Hence, the FGB index provides a robust measure. Furthermore, despite the documented substantial relevance of funding and financial development in enhancing ecological sustainability in extant studies, no consensus existed on how finance impacts environmental sustainability.

The study relied on a dataset from 44 African countries sourced between 1990 and 2020; and second-generation panel unit root, cointegration, and estimation procedures are employed. The essence is controlling for the panel dataset's cross-sectional dependence, heterogeneity, and endogeneity. Specifically, the cross-sectional autoregressive distributed lag (CS-ARDL) model derived the study's inferences. There is no known study to have adopted this approach in a renewable energy-ecological sustainability nexus for Africa. Empirically, the study demonstrated that renewable energy does not impact ecological sustainability without external debt and FGB. However, the inclusion of both variables indicated that while renewable energy and FGB enhanced environmental sustainability, external debt degenerated environmental sustainability in the short and long-term periods.

The rest of the paper shows Section 2 contains the reviewed literature; Section 3, the study's data and methodology; Section 4, the study findings and discussion; Section 5, the conclusions and policy implications.

2. Literature Review

2.1. Theoretical review

Empirical works have commonly examined the nexus between renewable energy consumption and ecological sustainability from the environmental Kuznets curve (EKC) perspective. Grossman and Krueger (1991) proposed the EKC hypothesis to evaluate different environmental atrophy and income per capita indicators. The theory states that ecological degradation and pollution are bound to rise during the initial stages of economic prosperity. However, later stages of economic growth reverse this effect by promoting ecological quality. Grossman and Krueger (1994 and 1995) further noted that three factors are responsible for the asymmetric association between environmental sustainability and economic growth. These factors are scale, composition, and technique effects. While the scale effect denotes the impact of a rise in pollution due to economic expansion, the composition effect represents the structural change in production from an agrarian to an industry and service-driven economy (Aladejare, 2020). This transformation leads to resource reallocation in the economy.

Third is the technique effect, which emphasises the role of technology in the ecological quality-economic prosperity relationship. Adopting efficient production processes and technology will likely enhance economic output and decelerate pollutant emissions per unit of production (Aladejare, 2020). Consequently, the EKC hypothesis is adopted for this study since the form of energy applied in the process of pursuing economic prosperity impacts the environment. However, the energy-ecological nexus cannot be complete without a significant public sector investment in infrastructural development. Likewise, through globalisation, the relevant role of interacting with other advanced or similar economies for financial aid in the quest for economic growth is acknowledged, particularly for developing countries. Thus, African economies have been encouraged to eliminate barriers to aid inflows of external financial portfolios and investments due to the urgency to fight poverty and deliver rapid economic prosperity in the continent. However, the quest for external financial investment in these countries has made them vulnerable to all forms of foreign financial aid and investment that can be ecologically detrimental.

2.2. Empirical review

2.2.1. Renewable energy-ecological sustainability nexus

Ansari et al. (2021) revealed through the fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS) and panel mean group (PMG) procedures that renewable energy reduces EFP in top renewable energy-consuming nations. Likewise, Yang et al. (2021) employed the augmented mean group (AMG) and common correlated effects mean group (CCEMG) techniques. They found that renewable energy consumption reduced EFP in Asia Pacific Economic Cooperation (APEC) economies. A study of 25 developing Asian countries conducted by Mohsin et al. (2021) applied the Hausman-Taylor regression (HTR) and robust random effect (RE) procedures. Findings from the study indicate the positive impact of renewable energy use on CO_2 emissions decline. Qayyum et al. (2021) demonstrated, using autoregressive distributed lag (ARDL) and vector error correction (VECM) models, that renewable energy consumption reduces CO_2 emissions in India. Chien et al. (2021) applied the method of moments quantile regression (MMQR) approach for a study on BRICS countries and concluded that renewable energy deteriorated CO_2 emissions. Also, Anwar et al. (2021) showed with the use of MMQR that renewable energy lowers CO_2 emissions in ASEAN countries.

Similarly, Miao et al. (2022) applied MMQR, FMOLS, DOLS, and fixed effects (FE) OLS methods for a study on newly industrialised countries (NICs). Findings from the research showed that renewable energy decelerates EFP. Suki et al. (2022) applied bootstrap ARDL and found the blessing effect of renewable energy on EFP for Malaysia. Chien (2022) further demonstrated using the MMQR technique that renewable energy consumption reduced CO_2 emissions in N-11 countries. Raihan and Tuspekova (2022) showed with the application of the ARDL, DOLS, FMOLS, and canonical cointegrating regression (CCR) that, renewable energy mitigates CO_2 emissions in Peru. Aladejare and Salihu (2023) applied FMOLS, DOLS, Driscoll-Kraay (D-K), and MMQR procedures in their analyses. They demonstrated that while an increase in brown energy utilisation exhausted resource productivity, green energy utilisation enhanced it from the lower to the higher quantiles in 40 developing economies.

Furthermore, Khan et al. (2022) demonstrated with generalised least squares (GLS), and panel-corrected standard errors (PCSE) models that renewable energy depreciates CO_2 emissions in BRICS countries. In contrast, Esquivias et al. (2022) revealed by applying the panel quantile regression that renewable energy raised CO_2 emissions for emerging Asian economies. Also, Kartal (2022) showed by applying multivariate adaptive regression splines that renewable energy consumption was partially significant in mitigating CO_2 emissions in the top-five carbon-emitting nations. Similarly, by using a two-step system generalised method of moments (GMM) and Dumitrescu-Hurlin (D-H) causality techniques, Cakmak and Acar (2022) revealed that renewable energy has no significant effect on EFP in oil-producing countries (Nigeria, USA, China, Canada, Brazil, Kuwait, Saudi Arabia, and Russia).

Also, Shayanmehr et al. (2023) revealed with the aid of MMQR, DOLS, FMOLS and GMM procedures that renewable energy is insignificant for EFP in countries with lower pollution. However, using bootstrap Fourier Granger causality in quantile analysis, Kartal et al. (2023) submitted that renewable energy consumption reduced CO_2, EFP, and load capacity factor (LCF) for the USA. Also, Lee et al. (2023) applied the computable general equilibrium (CGE) technique and concluded that renewable energy is beneficial for decreasing CO_2 emissions in China. Likewise, Ramzan et al. (2023) used non-parametric causality-in-quantiles algorithms approach to confirm the predictive power of renewable energy on EFP for the USA. Similarly, Bashir et al. (2023) employed CS-ARDL, FMOLS, AMG, and CCEMG approaches to confirm the EFP-reducing effect of renewable energy in top-10 manufacturing countries. Wang et al. (2023) further demonstrated with the system GMM and panel quantile approaches that renewable energy benefits EFP in G7 and E7 countries.

2.2.2. Foreign debt-ecological sustainability nexus

In their study of Turkey, Katircioglu and Clebi (2018) confirmed significant interaction between foreign debt stock and CO_2 emissions. Later, Akam et al. (2021) showed that foreign indebtedness aggravated CO_2 emissions in Heavily Indebted Poor Countries (HIPCs). Likewise, Bese (2021a) affirmed with the ARDL technique that external debt exacerbated CO_2 emissions in China. Also, Bese (2021b) confirmed the positive effect of foreign debt stock on

CO_2 emissions in India. Wu et al. (2021) showed that green financing mitigated CO_2 emissions in E7 and G7 economies. Sadiq et al. (2022) demonstrated using CS-ARDL, AMG, and CCEMG that foreign debt depreciated CO_2 emissions in BRICS countries. Also, Batmunkh et al. (2022) revealed with the aid of FE, RE, and pooled effect models that debt stock promotes temperature changes in Central Asian countries. Likewise, Akam et al. (2022) used the AMG method and confirmed the CO_2-emitting effect of external debt in South Africa and Algeria.

Also, Xu et al. (2022) applied the bootstrap ARDL and submitted that foreign debt is significant for enhancing Turkey's EFP quality. Samour and Adebayo (2022) demonstrated with the MMQR, CCEMG, and AMG methods that foreign debt worsened LCF in BRICS countries. In contrast, Bese and Friday (2022) adopted the ARDL method and confirmed the irrelevance of foreign debt for EFP in Turkey. However, using the FMOLS technique, Alhassan and Kwakwa (2022) proved a U-shaped impact of debt stock on CO_2 emissions for Ghana. Ramzan et al. (2023) established the predictive power of external debt on EFP for the USA. The study by Farooq et al. (2023) confirmed the CO_2-emitting effect of external debt in OIC countries. However, using AMG, FMOLS, and DOLS procedures, Zeraibi et al. (2023) affirmed that external debt reduces CO_2 emissions in emerging economies.

2.2.3. Financial globalisation-ecological sustainability nexus

Ulucak et al. (2020) showed in their study that FGB mitigated EFP in emerging countries. Ahmad et al. (2021a,b) later documented the reducing effect of FGB on EFP in G7 nations. Conversely, Zia et al. (2021) showed with the dynamic simulated ARDL method that FGB worsened EFP for China. Similarly, Yang et al. (2021) revealed that financial development adversely impacted EFP in Gulf cooperation council (GCC) countries. Khan et al. (2022) further indicated that financial development reduces CO_2 emissions in BRICS countries. Similarly, Sadiq et al. (2022) demonstrated that FGB worsened CO_2 emissions in BRICS countries. Miao et al. (2022) established that FGB enhanced EFP in NICs. Chishti and Sinha (2022) also showed that financial innovation reduces CO_2 emissions in BRICS countries.

Also, Adebayo (2022) confirmed using quantile-on-quantile regression that FGB diminishes CO_2 emissions in E7 economies. An enhancing effect of FGB on EFP was reported by Kihombo et al. (2022), who applied the continuously updated fully modified (CUP-FM) and continuously updated bias-corrected (CUP-BC) methods for West Asian and the Middle East (WAME) countries. In contrast, Akadiri et al. (2022) demonstrated that FGB increased LCF for India. Bashir et al. (2023) confirmed the depreciating effect of financial development on EFP in top-10 manufacturing countries. Wang et al. (2023) later demonstrated that FGB increases EFP in G7 and E7 countries. However, Ramzan et al. (2023) applied the time-varying rolling window method and confirmed the enhancing role of FGB for EFP in the United Kingdom. Also, Hasan and Du (2023) asserted that green financial development is essential in decelerating climate change per person in China. Similarly, Wu et al. (2023) applied the CS-ARDL technique and confirmed that financial development diminishes CO_2 emissions in Nordic economies.

2.3. Literature gap

From the above review, there is evidence to support the beneficial effect of renewable energy, external debt, and FGB on environmental quality. However, some other studies have reported their harmful and no impact on ecological quality, thus, leaving room for a further probe of these associations. Also, studies that have examined any of the three relationships for African countries are scant, constituting an enormous gap in the literature. Furthermore, many of these studies relied on CO_2 emissions to proxy ecological/environmental sustainability against the much more comprehensive EFP indicator. In addition, none of the reviewed studies determined the contemporaneous role of foreign indebtedness and FGB in the renewable energy-ecological sustainability nexus. Consequently, this study extends the literature on these fronts.

3. Study Data and Methodology

3.1. Data description

The study employed a dataset between 1990 and 2020 to assess the impact of renewable energy, external debt, and financial globalisation on ecological sustainability in 44 African countries. The country list is in Appendix Table A1, and their preference from 54 African countries is justified by data completeness and availability.

In this study, ecological sustainability represented the response variable and is indicated by the ecological footprint per capita. The measure provides a robust indicator of ecological quality in recent environmental and energy-related literature. EF uniquely incorporates the amount of various natural areas needed for economic prosperity. These natural spaces include forest resources, built-up land, crops and grazing lands, carbon space, and fishing grounds (Aladejare, 2020). Further justification for this measure stems from its link to the destructive tendencies energy consumption creates for the ecosystem, such as surface water degeneration, biodiversity loss, groundwater pollution, and soil erosion.

Furthermore, the study used four explanatory variables: external debt, renewable energy, financial globalisation, and economic growth. Due to the saving-investment gap in countries, external debt is a viable tool the public sector can deploy for investment in green economic and infrastructural development. Deliberately borrowing for ecological sustainability by governments, especially developing ones, is seldom widespread. Intuitively, environmental issues only recently began dominating the national and international discourse. In many countries, the diverse economic and socioeconomic challenges are still counted as more pressing challenges than ecological sustainability.

Also, the indicator for renewable energy is its share in total energy consumption. It is used in this study since energy consumption constitutes one of the essentials of a better life, and the socioeconomic stability of any economy depends on its accessibility. Thus, the growing carbon emissions and global warming ills have spurred the significant pursuit of renewable energy as a clean and sustainable alternative to fossil energy sources. As a result, renewable energy has the potential to provide energy safety and climate change.

FGB is the extent to which nations relax cross-border financial transactions. For this purpose, this study used the aggregate KOF FGB index because it combines de facto and de jure financial integration. While the de facto index captures the flow of foreign capital and the stocks of international assets and liabilities, the de jure component covers indicators of government policies and rules that aid the international flow of capital. These regulations and guidelines include constraints on investment, capital account openness and the number of foreign investment agreements (Gygli et al., 2019).

Economic growth is another explanatory variable used as a control indicator in the study. Its proxy is the gross domestic product (GDP) per capita. As the economy grows, the demand for more energy services for a higher industrial drive increases. Consequently, more resources are deployed to meet energy needs and sustain economic growth. However, the significance of such economic growth on environmental sustainability depends on the size and productivity of the country's real sector. Table 1 further captures the study variables, their measurement and sources.

Table 1. Variable description.

Variable	Measurement	Source	Symbol
Ecological sustainability	Ecological footprint global hectares (gha) per capita	GFN (2022)	efp
External debt	Total external debt % of GDP	WDI (2022)	edy
Renewable energy	Renewable energy % of total energy consumption	WDI (2022)	rwe
Financial globalisation	Weight in percentage	Gygli et al. (2019)	fgb
Economic growth	GDP per capita growth (%)	WDI (2022)	ypc

Source: Authors' computation.

3.2. Methodology

Based on the study objectives, the study estimated two relationships. Objective one, which is to determine the effect of renewable energy on ecological sustainability, is as follows:

$$efp_{it} = \alpha_0 + \alpha_1 rwe_{it} + \alpha_2 ypc_{it} + \alpha_3 ypc_{it}^2 + \mu_{it} \quad (1)$$

where ypc_{it}^2 denote the square of economic growth representing the later stages of economic prosperity in the EKC hypothesis. Objective two, which examines the role of external debt and FGB in the renewable energy-environmental sustainability relationship, is as follows:

$$efp_{it} = \beta_0 + \beta_1 rwe_{it} + \beta_2 rwe_{it} + \beta_3 edy_{it} + \beta_4 fgb_{it} + \beta_5 ypc_{it} + \beta_6 ypc_{it}^2 + \varepsilon_{it} \quad (2)$$

These two Equations express the impact of the independent variables on the dependent variable.

3.2.1. Estimation procedure

The econometric analysis of this study begins with testing for cross-sectional dependency test (CSD). This test is essential as a pre-condition for obtaining good outcomes since ignoring the CSD effect in a panel analysis can bias the regression through spurious regression results. Consequently, the study adopted four CSD tests for a robust output, and they include Breusch and Pagan's (1980) Lagrange multiplier (LM) test, Pesaran's (2004) scaled LM test, Pesaran's (2004) CSD test, and the Baltagi et al. (2012) bias-corrected scaled LM test.

Similarly, the susceptibleness of panel data analysis to slope homogeneity, arising from different economic and demographic configurations of cross-sectional units, may produce misleading regression results (Aladejare and Musa, 2023; Aladejare, 2023a, d). Therefore, having a slope heterogeneity test is necessary when evaluating panel datasets. The procedure makes it easier to conclude the coefficients' homogeneity or heterogeneity across cross-sections. Consequently, two homogeneity tests, namely Swamy (1970) and the Pesaran and Yamagata (2008) adjusted version, was used in this study.

Furthermore, the validation of CSD and heterogeneity in the panel dataset informed the use of unit root and cointegration tests incorporating both effects. For unit root, the study combined first, and second-generation tests that correct these effects. The panel unit root methods are Madalla and Wu (1999), Pesaran (2003) cross-sectional augmented Dickey-Fuller (CADF), and Pesaran (2007) cross-sectional Im Pesaran and Shin (CIPS). Also, we applied the Westerlund (2007) error correction model (ECM)-based cointegration technique. Aside from correcting for CSD and heterogeneity, this long-run test can suitably combine variables of different order of stationarity in a model (Aladejare and Musa, 2023; Aladejare, 2023b, d).

3.2.2. The cross-sectional augmented ARDL (CS-ARDL) approach

Traditional econometric procedures are vulnerable to spurious outputs in the presence of CSD and heterogeneity in panel dataset analysis (Chudik et al., 2017). Thus, as a remedy, the CS-ARDL approach was developed to handle biases such as CSD, endogeneity, heterogeneity, non-stationarity, and omitted variables in panel data estimation (Chudik et al., 2017; Bindi, 2018). The CS-ARDL's structure is built on augmenting the first-generation (mainstream ARDL) technique by integrating the response series, cross-section means of covariates, and their lags. Also, the method regulates cross-sections' structural identities to produce unique short and long-term explanatory coefficient effects on the dependent series. Furthermore, the CS-ARDL approach is known to outdo the panel ARDL model, especially when $30 \leq T < 100$ (Chudik et al., 2017); thus, it's suitable for this study.

Consequently, the CS-ARDL technique is as follows:

$$y_{it} = \propto_i + \sum_{i=1}^{p} \vartheta_{i1}\, y_{i,t-1} + \sum_{1=0}^{q} \omega'_{i1}\, X_{i,t-1} + \varepsilon_{it} \tag{3}$$

By rewriting Equation 3, the CS-ARDL model transforms to:

$$y_{it} = \propto_i + \sum_{i=1}^{p} \vartheta_{i1}\, y_{i,t-1} + \sum_{1=0}^{q} \omega'_{i1}\, X_{i,t-1} + \sum_{1=0}^{q} \omega'_{i,1}\, \overline{Z_{t-1}} + \varepsilon_{it} \tag{4}$$

$$\bar{Z}_t = \left(\bar{y}_t, \overline{X'_t}\right) \tag{5}$$

$$\varepsilon_{it} = \Pi'_i f_t + \mu_{it} \tag{6}$$

where Equation 5 is denoted by $\bar{Z}_t$ is the cross-sectional averages of the covariates for the response variable $(\bar{y}_t)$ and the explanatory variable $(\overline{X'_t})$. f_t signifies the unobserved common component responsible for the dependency of cross-sectional units. The common elements are given through a detrending process of the cross-sectional means and lagged through Equation 5. Equation 4 is estimated by a pooled mean group (PMG) approach, and Equation 7 provides the long-term coefficients.

$$\widehat{\eta_\iota} = \frac{\sum_{i=0}^{q} \widehat{\omega'_{1\iota}}}{1 - \sum_{i=0}^{q} \widehat{\vartheta_{1\iota}}} \tag{7}$$

Further transformation of Equation 3, as expressed in Equation 8, will yield the ECM of the model (Ditzen, 2019).

$$\Delta y_{it} = \propto_i \left[y_{i,t-1} - \emptyset_i X_{it}\right] - \sum_{i=1}^{p} \vartheta_{i1}\, y_{i,t-1} + \sum_{1=0}^{q} \omega'_{i1}\, X_{i,t-1} + \sum_{1=0}^{q} \omega'_{i,1}\, \overline{Z_{t-1}} + \varepsilon_{it} \tag{8}$$

where:

$$\widehat{\emptyset_\iota} = \frac{\sum_{i=0}^{q} \widehat{\omega'_{1\iota}}}{\widehat{\propto}_i} \tag{9}$$

4. Estimated Results and Discussions

4.1. Descriptive statistic test outcome

Table 2 reveals the mean efp for the African countries as 1.52 (gha) approximately. This value marginally falls short of the world's mean (1.75 gha) (GFN, 2022). Table 2 demonstrates that the average debt-to-GDP of 51.66% exceeds the prudential baseline of 40% for developing and emerging economies required for fiscal sustainability (Choudhury and Islam, 2016; Aladejare, 2021; Aladejare, 2023d). The mean renewable energy as a share of total energy consumption (66.60%) is relatively high, indicating the growth of the energy source in the continent. Meanwhile, Africa's mean financial globalisation index is approximately 45.1, falling short of the world's average value of 55 (Gygli et al., 2019), which indicates a lower preference for the African market regarding foreign capital flow. Also, evidence in Table 2 reveals that the mean income growth for African countries is approximately 1.15%. This value marginally lies below the world's mean of 1.7% for the study period (WDI, 2022); and implies a slower income convergence rate between the continent and other parts of the world.

Table 2. Aggregate descriptive statistic.

Variable		Mean	Std. Dev.	Min	Max	Observations
efp	Overall	1.517	0.774	0.284	4.915	N = 1364
	Between		0.611	0.369	3.304	n = 44
	Within		0.484	0.240	4.508	T = 31
edy	Overall	51.655	106.431	2.814	2056.541	N = 1364
	Between		60.123	10.818	418.815	n = 44
	Within		88.274	-350.738	1689.381	T = 31
rwe	Overall	66.600	27.832	0.6	0.06	N = 1364
	Between		27.373	0.320	0.320	n = 44
	Within		6.468	45.030	45.030	T = 31
fgb	Overall	45.1151	11.475	15	87	N = 1364
	Between		9.387	27.710	66.032	n = 44
	Within		6.745	20.405	66.438	T = 31
ypc	Overall	1.148	5.964	-50.047	90.14	N = 1364
	Between		1.439	-1.801	4.216	n = 44
	Within		5.792	-49.747	91.952	T = 31

Source: Authors' Estimated Output.

4.2. Correlation matrix and cross-sectional dependency results

Presented in Table 3 are the correlation and variance inflation factor (VIF) tests. Both tests confirmed the level of collinearity between the study covariates. In the upper panel of Table 3, the correlation test showed weak multi-collinearity between the independent variables. Similarly, the VIF report in the lower forum shows the same conclusion, judging by the rule of thumb that VIF values ranging between 1 and 5 imply a moderate correlation. Thus, since the mean VIF for the study is 1.07, we conclude that there is less multi-collinearity between the study's regressors.

Table 3. Correlation matrix.

	efp	edy	rwe	fgb	ypc
efp	1				
edy	-0.068	1			
rwe	-0.482	0.087	1		
fgb	0.073	-0.143	-0.267	1	
ypc	0.031	-0.093	0.054	0.029	1
	VIF	1/VIF			
fgb	1.11	0.900			
rwe	1.10	0.911			
edy	1.05	0.954			
ypc	1.01	0.988			

Mean VIF: 1.07. Source: Authors' Estimated Output.

Results in Table 4 demonstrate the four CSD tests applied. Evidence reveals the rejection of the null hypothesis of cross-sectional independence. Therefore, given the study variables, the conclusion is that there is significant CSD across the cross-sections.

Table 4. CSD test output.

Variable	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CSD
efp	8357.857***	170.399***	169.665***	8.295***
edy	8899.645***	182.855***	182.121***	47.407***
rwe	10870.82***	228.172***	227.439***	69.070***

fgb	5634.180***	107.781***	107.048***	17.608***
ypc	1885.167***	21.591***	20.858***	25.327***

*Note: *** indicates statistical significance at 1%. H_o: No cross-section dependence. Source: Authors' Estimated Output.*

4.3. Slope heterogeneity and unit root outcomes

Table 5 captures the slope heterogeneity test outcome. Inference derived from the output supported the insignificance of the null hypothesis stating homogenous slope parameters and, instead, justifying the alternative hypothesis confirms slope heterogeneity in the study variables' parameters.

Table 5. Slope heterogeneity Test.

Test-Statistics	Coefficient	p-value
$\bar{\Delta}$	27.346	0.000***
$\bar{\Delta}_{adjusted}$	30.338	0.000***
H_0	Slope coefficients are homogenous.	

*Note: *** indicates statistical significance at 1%. Source: Authors' Estimated Output.*

Furthermore, the confirmation of CSD and slope heterogeneity in the panel dataset informed implementing unit root tests enabled with the capabilities to correct both issues. Thus, Table 6 shows the outcome of first and second-generation panel unit root tests designed for tackling CSD and heterogeneity challenges. Also, table 6 expressed that except for the economic growth indicator, which revealed stationary at level, all other variables attained stationarity at the first difference.

Table 6. Unit root test output.

	First-generation unit root		Second-generation unit root				
Variable	Maddala and Wu (1999)		Pesaran's CADF (2003)		Pesaran's CIPS (2007)		
	Without trend	With trend	Without trend	With trend	Without trend	With trend	Decision
efp	84.451	91.254	-3.919***[b]	-4.041***[b]	1.962	2.480	I(1)
edy	49.300	37.725	-3.113***[b]	-3.365***[b]	2.944	4.337	I(1)
rwe	48.391	56.994	-3.629***[b]	-3.759***[b]	-0.788	2.801	I(1)
fgb	153.846***	146.694***	-4.049***[b]	-4.158***[b]	-0.921	-0.849	I(1)
ypc	349.879***	281.974***	-3.262***[b]	-3.711***[a]	-10.528***	-10.333***	I(0)
H_0	Series is I(1)		Series is non-stationary		Series is I(1)		

*Note: a and b represent stationarity at the level and first difference, respectively, while *** indicates statistical significance at 1%. Source: Authors' Computation.*

4.4. Westerlund panel cointegration output

After determining the variables' stationarity condition, the Westerlund cointegration procedure ascertained their long-term relationship. The technique, as prior noted, efficiently tackles CSD and heterogeneity issues in panel data analysis. Table 7 contains the test output, which shows the rejection of the null hypothesis of no long-run association. Instead, the test validated the alternative view that the study series has a long-term relationship.

Table 7. Westerlund panel CSD cointegration Test.

Equation 1		Equation 2	
Statistic	Value	Statistic	Value
G_t	-2.007***	G_t	-2.867***
G_a	-7.716***	G_a	-11.710***
P_t	-8.934***	P_t	-15.978***
P_a	-4.545***	P_a	-8.795***
H_0: No cointegration			

*Note: *** indicates statistical significance at 1%6, respectively. Source: Authors' computation.*

4.5. CS-ARDL estimated result

Table 8 demonstrates the outcome for the two equations capturing the two study objectives. In the first panel, renewable energy consumption indicates an insignificant effect on ecological sustainability in the short and long term. Similarly, economic growth and its square showed no substantial short and long-run impact on environmental sustainability.

However, the second panel of Table 8 reveals that renewable energy consumption and financial globalisation significantly negatively impact ecological sustainability in the short and long run. Conversely, the coefficient of external debt shows a positive relationship with environmental sustainability in the short and long term. In contrast, economic growth and its square exhibit an insignificant short- and long-term effect on environmental quality.

Furthermore, both equations' adjustment factor (ECM) is rightly signed and statistically significant. Also, they are similar in response to long-run adjustment because, while the value for Equation 1 suggests about nine months, the value for Equation 2 indicates about eight months of adjustment period from short-term distortion to long-term equilibrium path.

Table 8. CS-ARDL long-term and short-term results.

Variable	Long-run output			Short-run output		
	Coefficient	z-stat	p-value	Coefficient	z-stat	p-value
Equ.1: Dependent variable efp						
rwe	-0.008	-1.39	0.165	-0.007	-1.43	0.153
ypc	0.002	1.09	0.274	0.002	1.27	0.204
ypc^2	-0.0001	-0.29	0.770	-0.0001	-0.24	0.812
$constant$	0.009	0.10	0.918	0.013	0.16	0.874
$ecm(-1)$				-1.112***	-37.44	0.000
R^2	0.71					
Equ.2: Dependent variable efp						
rwe	-0.005*	-1.69	0.092	-0.005**	-1.65	0.099
edy	0.003*	1.89	0.059	0.003*	1.90	0.058
fgb	-0.003**	-2.01	0.044	-0.004*	-1.94	0.053
ypc	0.002	1.03	0.304	0.002	1.10	0.272
ypc^2	-0.0003	-0.68	0.499	-0.0003	-0.66	0.508
$constant$	0.289	1.28	0.199	0.331	1.21	0.227
$ecm(-1)$				-1.193***	-35.44	0.000
R^2	0.72					

*Note: *, **, and *** indicate statistical significance at 10%, 5% and 1%, respectively. Source: Authors' Computation.*

4.6. Discussion of findings

Based on the estimated CS-ARDL output for Equation 1, renewable energy does not have the individual strength to trigger environmental sustainability. However, the result for Equation 2 reveals that with the inclusion of foreign debt and financial globalisation, renewable energy consumption encouraged ecological sustainability both in the short and long term.

Based on the predictions from Equation 2, it thus indicates that renewable energy decelerates environmental risks and provides green and sustainable energy means for African countries. This finding aligns with empirical works such as Chien (2022), Khan et al. (2022), Miao et al. (2022), Kartal et al. (2023), and Wang et al. (2022) for N-11 economies, BRICS nations, NICs USA, and G7 and E7 countries, respectively. These studies revealed that renewable energy usage promotes ecological protection. Conversely, the result contradicts submissions in Esquivias et al. (2022), Cakmak and Acar (2022), and Shayanmehr et al. (2023) for Asian emerging countries, oil-producing economies, and countries with lower emissions, respectively. These studies confirmed renewable energy consumption's insignificant or reduced effect on environmental quality.

However, the outcome of this study demonstrates that renewable energy aid energy demand by producing a safe transition from brown energy means to sustainable and eco-friendly sources. Thus, accelerating renewable energy use diminishes the negative impacts of energy consumption on the environment. Also, renewable energy aids the reduction of dependence on energy imports and other fossil fuels, thereby promoting a cleaner environment. Consequently, improving the consumption of renewable energy sources is a sure means to environmental sustainability in the short and long-term periods. Aside from the fact that renewable energy sources are abundant in the wind, solar, sun, waste, and Earth's heat, they are replenished by nature. Their sustained use yields minute to no atmospheric pollutants or GHG emissions.

The positive effect of external debt on environmental sustainability indicates that the former aggravates ecological risk. Thus, the implication is that foreign borrowing prioritisation for factors that can promote environmental sustainability is lacking. This outcome supports findings by Akam et al. (2021), Sadiq et al. (2022), Batmunkh et al. (2022) and Farooq et al. (2023) for HIPCs, BRICS countries, Central Asia countries, and OIC countries, respectively, that debt stock deteriorates ecological sustainability. In contrast, the result opposed the findings in Sadiq et al. (2022), Bese and Friday (2022), and Zeraibi et al. (2023) for BRICS countries, Turkey, and emerging economies, respectively. As previously noted, governments rarely borrow, especially those in the developing world, to pursue green economic growth. Instead, it is common to deploy external debt for social and economic infrastructures such as roads, dams, transportation systems, housing, factories, etc., which serve as economic growth catalysts.

However, as in many countries, the citing and construction of these projects often neglect environmental sustainability, thereby creating deforestation, biodiversity loss, soil pollution, air pollution, and water pollution. For instance, studies such as Nyangena et al. (2019), Qayyum et al. (2021), Younis et al. (2021), and Yang and Khan (2022) for East African countries, South Asian economies, BRICS countries, and IEA member countries, respectively concluded that urban growth significantly results in ecological degradation. Similarly, studies such as UNCTAD (2020) and Aladejare and Nyiputen (2023) have found that the quest for industrialisation exacerbates poor environmental quality in African economies due to ineffective ecological protection measures. Hence, environmental sustainability cannot be assured when countries fail to use external borrowing for green economic growth and development.

The inference that financial globalisation exacts an enhancing effect on ecological sustainability is plausible. It aligns with findings in extant studies such as Ulucak et al. (2020), Adebayo (2022), Kihombo et al. (2022), Ramzan et al. (2023), and Hasan and Du (2023), for emerging economies, E7 economies, WAME countries, United Kingdom, and China, respectively. However, the result contradicts submissions in Zia et al. (2021), Yang et al. (2021), Sadiq et al. (2022), Akadiri et al. (2022), and Bashir et al. (2023) for China, GCC nations, BRICS economies, India, and top-10 manufacturing economies, respectively. However, the negative output implies that as financial globalisation increases, it enhances ecological sustainability. This effect may relate to the fact that financial globalisation can assist countries in their transition from brown energy to other energy sources that integrate green and clean energy sources into the countries' national energy mix (Kirikkaleli et al., 2022). Also, financial globalisation can produce a green technology spill-over effect capable of mitigating environmental atrophy.

Consequently, since financial globalisation decreases the ecological degradation of African countries, financial globalisation is, thus, an essential mechanism necessary for terminating the tradeoff between economic growth and environmental degeneration. Furthermore, technological diffusion emanating from a sustainable rise in foreign direct investment inflow (FDI) to African countries may be another reason for the eco-friendly role of financial globalisation in these nations. Moreover, when FDI and efficient technology are available to boost economic production, limited resources or input are used in the production process. Thus, this measure will aid the reduction of environmental pollution since advanced technology can yield more output using less input.

Although earlier studies have suggested the significance of economic growth for environmental degeneration (Bhat et al., 2021; Li et al., 2021; Usman et al., 2022; Chen et al., 2022; Hassan et al., 2022), the CS-ARDL output in Table 8 reveals otherwise for both estimated equations. Economic growth accelerates energy demand for a higher industrial drive. Hence, more resources for the energy needs required to sustain economic growth are deployed. However, how substantial the effect of economic prosperity on ecological sustainability is, relies on the size and productivity of the real sector in the country. Many African economies are still in their early stages of development, depending on the production of primary commodities for growth and relying primarily on imports for finished industrialised goods. Also, the implementation of import substitution policy in most African countries is slow due to capital shortage. In such a situation, economic growth's environmental impact may be insignificant. The implication of this effect further accounts for the insignificance of the squared economic growth, invalidating the EKC hypothesis in African countries. Thus, the invalid EKC hypothesis supports extant studies such as Lin et al. (2016), Aladejare (2020), Tachega et al. (2021), and Ouedraogo et al. (2022) for African countries.

5. Concluding Remarks

Since the last decade, ecological preservation has become a critically debated topic in developing and developed nations. Hence, to ensure environmental sustainability, countries and international bodies have been canvassing for measures that support severe restrictions to protect the Earth's biodiversity. Without such an approach, sustaining the ecological quality needed for sustainable growth and development will be a mirage if current GHG levels are not tamed. Hence, this study's goal is two-fold: to determine the sole effect of renewable energy consumption on ecological sustainability and secondly, to identify the roles of external debt and financial globalisation in the renewable energy-ecological sustainability association for 44 African countries. Second-generation estimation techniques were employed and deduced inferences from the CS-ARDL method used in the study. The study empirically demonstrated that renewable energy is insignificant for ecological sustainability without debt stock and financial globalisation. However, the inclusion of both variables revealed that while renewable energy and financial globalisation accelerated ecological sustainability, external debt worsened it in the short and long-term periods.

Based on the study findings, some policy implications are proposed. First, given the productive benefits of renewable energy use to human and environmental well-being, policymakers must execute clean energy portfolios by restricting brown energy use by considering introducing a significant amount of carbon tax or emission permit and incentivising businesses to adopt green technologies. This measure will ensure that renewable energy growth and investment are explored for sustainable development—a pollution-free economy, and enhanced human living conditions. Also, countries should be intentional in incorporating and implementing renewable energy transition paths in their national energy policy to promote low-emission energy systems.

Second, with the possible harmful effect of foreign debt stock on the environment, policymakers should begin to borrow for ecological sustainability consciously. One such way is to invest in green transportation, infrastructure, energy, agriculture, manufacturing, and land use. When the public sector channel foreign debt to this green ventures, ecological quality will be enhanced since debt stocks are invested in infrastructures and assets that cut down on carbon emissions and improve resources and energy efficiency, and equally accelerate the reduction of biodiversity loss. It is also necessary to maintain impeccable accountability in the disbursement of the borrowed funds to avoid misappropriation, corruption, and ecologically-degrading investments.

Third, since financial globalisation is eco-friendly, policymakers should be particular about enhancing trade and financial relations that are not just FDI boosting, but environmentally friendly. By encouraging the growth of such association, FDI inflows to the continent are bound to rub off positively on domestic financial markets by complementing finance for environmental protection and the transfer and production of green technologies. Accordingly, countries must imbibe international sustainable environmental guidelines that promote stringent ecological regulations when seeking international capital projects. Policymakers will need to constrain projects with outdated technologies from entering the economy by implementing heavy dumping duties. At the same time, tax holidays and other incentives to encourage inflows of efficient capital goods are essential. This approach will improve export capacity and facilitate environmental sustainability in producing goods and services.

Future African studies can determine the role of human capital in renewable energy, external debt, financial globalisation and ecological sustainability relationship. This study could not capture human capital due to data incompleteness and unavailability for some African countries, hence its constraint.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Author contributions

SAA conceived the idea, wrote the introduction, SAA collected and analysed the data, interpreted the results, MIY reviewed the required literature, MIY edited the manuscript, SAA wrote the methodology section, SAA and MIY provided the relevant policy directions, SAA and MIY read and approved the final manuscript.

Appendix

Table A1. 44 study countries.

Algeria	Congo Republic	Lesotho	Rwanda
Angola	Cote d'Ivoire	Liberia	Senegal
Benin	Egypt	Madagascar	Sierra Leone
Botswana	Eswatini	Malawi	South Africa
Burkina Faso	Ethiopia	Mali	Sudan
Burundi	Gabon	Mauritania	Tanzania
Cabo Verde	Gambia, The	Mauritius	Togo
Cameroon	Ghana	Morocco	Tunisia
Central African Republic	Guinea	Mozambique	Uganda
Chad	Guinea-Bissau	Niger	Zambia
Congo, Democratic Republic	Kenya	Nigeria	Zimbabwe

Source: Authors' compilation.

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