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Towards a Green Future for Sub-Saharan Africa: Do electricity access and public debt drive environmental progress?

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Stephen K. Dimnwobi, Kingsley I. Okere, Bernard C. Azolibe & Kingsley C. Onyenwife

Abstract

The combination of rising debt levels, poor electricity access, and environmental deterioration could threaten the attainment of the Sustainable Development Goals (SDGs). Hence, this inquiry examined the implications of public borrowing and access to electricity on environmental sustainability (proxied by ecological footprint (ECOL)and carbon dioxide (CO_2) emissions) in Sub-Saharan Africa (SSA), largely overlooked in the literature. In addition to pre-estimation, diagnostic and robustness checks utilized in the study, the instrumental variable generalized method of moment(IV-GMM) approach is employedto examine annual data from 39 SSA economies between 2005 and 2018. The key findings indicate that public debt negatively influences environmental sustainability in the region, while access to electricity exerts a positive and significant impact on environmental sustainability. The study provides recommendations for SSA policymakers to significantly reduce pollution and protect the environment which is vital for sustainable development.

Keywords: Environmental sustainability, SSA, Public debt, Electricity access, Ecological Footprint, Carbon Emission.

1. Introduction

The greatest threat to world welfare and prosperity is environmental deterioration (Pan & Dong, 2023; Pan, Dong & Du, 2023). The United Nations SDGs report places a strong emphasis on environmental challenges and highlights that one of the biggest barriers to social welfare and sustainable development is environmental deterioration (United Nations 2019). Hence, advancing environmental quality has become a very strategic global decision for guaranteeing sustainable development and promoting social welfare (Kahouli et al. 2022; Yu et al, 2023). As a result, deepening the comprehension of factors that causes ecological devastation is essential for promoting social welfare and accomplishing sustainable development objectives

Public debt represents a key element that affects environmental pollution. The major reason why nations borrow is to close the savings-investment gap and decrease current account deficits (Katircioglu and Celebi 2018). The environment is impacted both directly and indirectly by public debt. For the direct effect, it is presumed that the decision makers employ public borrowing to fund ecological sustainability initiatives by funding ecologically beneficial R&D and renewable energy projects, which eventually help to improve the quality of the environment (Farooq et al., 2023; Onuoha et al., 2023a; Onuoha et al., 2023b). But a high level of public debt may make it difficult to finance renewable energy initiatives while also restricting governments' capacity to provide funding for research into renewable energy solutions. Additionally, an increase in debt could force the government to reduce expenditures and investments to close the budget deficit. As a result, spending and investment in renewable energy sources may be reduced, which could lead to less efficient use of clean energy (Farooq et al., 2023; Onuoha et al., 2023a; Onuoha et al., 2023b). Government debt indirectly harms the environment through economic expansion. An adequate debt level is thought to boost capital inflow, promote investment, and improve economic performance. Consequently, a change in GDP changes the levels of energy consumption, which may affect environmental deterioration (Farooq et al., 2023; Onuoha et al., 2023a; Onuoha et al., 2023b).

Moreover, changes in electricity access around the world raise some issues that are relevant to the objectives of sustainable development (Bilgili et al. 2022). The most noteworthy debate dwells around the possibility of an alignment or trade-off between electricity access and climate change action goals (Jin et al. 2018; Cohen et al. 2021). The extant studies on this subject are divided into two categories: "win-win and trade-off" strategies with the former averring that having access to electricity improves environmental sustainability while lowering energy insecurity and poverty. This rationale holds that the availability of electricity encourages economic expansion, boosts prosperity and lowers poverty (Apergis and Katsaiti, 2018; Baloch et al. 2020). As the economy continues to expand, countries experience technical advancement and structural change, while innovative capacity and human capital accumulation increase with time. These changes lead to the emergence of clean, environmentally friendly production techniques as well as an improvement in environmental protection (Bilgili et al 2022; Kahouli et al 2022). The validity of this win-win approach is confirmed by Ansari et al (2022) and Bilgili et al (2022). The trade-off strategy posits the existence of a contradiction between policies that should be put in place to support economic advancement and measures to guarantee environmental sustainability. Electricity accessibility leads to ecologicaldestruction while addressing energy insecurity in particular, and alleviating poverty in general (Koçak et al. 2019). This view equally holds that access to electricity increases direct energy use and production activities, which might result in greenhouse gas emissions and ecological deterioration. Several studies have confirmed that electricity access undermines environmental sustainability (Hishan et al. 2019; Dumor et al. 2022; Hassan et al. 2022)

Sub-Saharan Africa (SSA) represents an ideal case study owing to these three-pronged motivations. First, despite being the world's lowest contributor of carbon emissions, SSA is recognized as the most sensitive to climate change challenges due to the nature of the region's economies and poor infrastructure(Alhassan 2021; Dimnwobi et al. 2021; Kwakwa et al. 2022; Nchofoung andAsongu, 2022; Okafor et al. 2022). For instance, the widespread flooding across the region in 2020 affected many lives and properties (WMO, 2021). Despite the commitment to attain a green economy, as seen by its participation in international climate discussions, the region has witnessed a considerable increase in CO_2 emissions, going from 402,373kt in 1990 to 823,770kt in 2019. During the same period, other regions witnessed significant CO_2 emissions reductions (World Bank 2020). This demonstrates that SSA may likely witness a rise in CO_2 emissions in the near future despite efforts being undertaken globally to decrease emissions (Nchofoung&Asongu, 2022).

Second, SSA has the lowest global electrification rate despite having an abundance of energy resources (Dimnwobi et al. 2022a; Dimnwobi et al. 2022b). In SSA, the average electrification rate is 48.2% against the global average of 90.4% evident in the continuous rise in the number of persons without access to power in the region, while other regions record more access (IEA 2020a; World Bank 2020). The recent pandemic has raised the immiseration of the populace and as documented by an International Energy Agency (IEA) report, the proportion of individuals in SSA without electricity access increased by 2% in 2020 relative to the level before the pandemic (IEA 2020b). Similarly, around 905 million individuals in the region are unable to adopt contemporary cooking techniques necessitating 848 million people from the region to depend on dirty fuels which degrade the environment (IEA 2019). People lacking electricity access are unable to employ contemporary cooking methods, as a result, they select affordable and accessible fuels like fossil fuels or firewood which damage the environment (Dimnwobi et al. 2022c). Similarly, Reyes et al. (2019) and Yu et al. (2022) show that inability to employ contemporary cooking facilities expands fuelwood consumption thereby lowering air standards. Third, public debt to GDP in the region grew from 26.7% in 2010 to 57.8% in 2020 (IMF 2021). The fiscal flexibility offered by debt reduction programs, along with improved global liquidity and higher growth rates, has resulted in SSA countries borrowing to fund infrastructure and development projects. Public debt is used as a source of finance for environmental programs in addition to its traditional relevance in public sector economics literature (Hashemizadeh et al. 2021).

The lingering inquiry continues to persist: Are electricity access and public debt influential factors in promoting environmental advancements? To address this inquiry, it becomes crucial to comprehend the response of SSA to a greener environment amidst climate uncertainties, as well as whether the interplay between electricity access and public debt within the continent amplifies or mitigates the impact of environmental sustainability. Electricity access and public debt have significant influence mechanisms on environmental sustainability. Improved electricity access, particularly through renewable energy sources, reduces greenhouse gas emissions and dependence on fossil fuels while enabling the adoption of energy-efficient technologies (Zeraibi, et al., 2023). Public debt can be leveraged to fund sustainable infrastructure projects and support the implementation of environmental policies and regulations. It can also facilitate the issuance of green bonds and financing mechanisms for environmentally friendly initiatives (Hakura, 2020;Boly, et al., 2022). By combining these efforts, electricity access and public debt can contribute to mitigating environmental impact, promoting sustainable development, and fostering a transition towards a more environmentally sustainable future (Dimnwobi et al., 2023; Zeraibi, et al., 2023).

Given the foregoing premise, this study expands the literature into six aspects. (1) Prior research has solely focused on connections between electricity access and environmental pollution, and debt and environmental pollution. Our study assessed the connections between electricity access, public debt and environmental pollution in SSA. To our knowledge, this represents the pioneering attempt at assessing the tripartite connections between electricity access, public debt and environmental pollution in the literature (2) Unlike prior studies, we utilized ecological footprint (ECOL) to proxy for environmental sustainability. The ECOL is a composite indicator of ecological deterioration that compares the amount of nature accessible for consumption to the amount consumed. It serves as a comprehensive measure of environmental stress brought on by human activity and corresponds to both ecological declines brought on by human consumption activities and the biosphere's capacity for natural regeneration. According to Wackernagel and Rees (1996), the ECOL is determined by assessing the amount of capital required to meet a nation's resource needs and waste disposal. The six sub-components that comprise the overall ECOL are cropland, fishing grounds, grazing land, developed land, forests, and land for carbon needs (Bello et al., 2022). In numerous aspects, the ECOL is an important environmental aggregate indicator. First, it is meticulously created to demonstrate how consumption patterns and waste behaviour affect environmental quality. Second, it is more than just a potential tool for gauging the planet's many frontiers and the level of human pressures on them, it also helps private citizens, community leaders, and nations to comprehend how their actions influence the global environment, maximizes the return on investment in community initiatives and promotes the citizen's welfare (Kazemzadeh et al., 2023). Because it captures a variety of human demands on nature rather than merely the quantity of carbon generated and sequestered in the atmosphere, the ecological footprint may broaden the discourse about a sustainable environment beyond the challenge of global warming and climate change (Charfeddine&Mrabet, 2017). It provides a framework for setting goals, selecting several sets of strategic plans, and assessing performance in relation to preset goals. (Ulucak&Apergis, 2018). Besides, the ECOL has been widely applied by past environmental scholars (Bello et al., 2022; Kazemzadeh et al., 2023; Kibria, 2023) in assessing ecological performance (3) In addition to ECOL, we also employed CO_2 emissions as an additional indicator of ecological damage. The justification for using these two variables is that electricity access and public debt could contribute to various kinds of environmental degradation. As a result, we employed CO_2 emissions and ECOL as a broader measure of environmental pollution. This is essential because the impacts of each explanatory variable may vary for different target variables, necessitating various policy responses (4) The study adopts the instrumental variable generalized method of moment (IV-GMM) and two-stage least squares (2SLS) method. These estimators are useful in resolving econometric issues like endogeneity, variable omissions and reverse causality (5) We focused on a region with rising debt levels, and poor electricity access as well as one of the world's most vulnerable regions to climate change consequences. The outcome of this research endeavour could provide policymakers with a strategy for reducing the harmful consequences of environmental degradation (6) Environmental sustainability is a top concern for policymakers, energy economists and environmentalists, hence, the outcome of this inquiry will assist policymakers to provide sufficient and succinct policies for maintaining a healthy environment without impeding economic progress.

The study continues in the following direction: Section 2 contains related literature while section 3 expoundson the study's methodology. Section 4 shows the empirical outcomes. The conclusion is provided in Section 5, along with relevant policy propositions.

2. Literature review

The theoretical foundation of this inquiry is the Environmental Kuznets Curve (EKC)popularized by Grossman and Krueger (1991; 1995) which acknowledges thatsignificant factors contribute to environmental degradation, postulating that economic growth exacerbates several environmental pollution indicators. However, once a certain amount of income is reached, continuing economic progress will drive environmental sustainability.

Two literary threads are reviewed in this section namely, electricity access and environment representing the first strand and public debt and the environment which represents the second strand. In a study of African economies from 1980 to 2020, Dumor et al (2022) applied the dynamic auto-regressive distributive lag (ARDL) model to document that electricity access hampers environmental sustainability. A study by Bilgili et al (2022) verified the influence of electricity access on environmental deterioration in 36 Asian countries and found that expanding electricity accessibility reduces carbon emissions. Hassan et al. (2022) discovered that the pace of ecological damage is considerably accelerated by electricity access in emerging economies from 1989 and 2016. In SSA between 1995 and 2018, Ansari et al (2022) documented that electricity access boosts the quality of the environment. Using a similar scope, Mewamba-Chekem and Noumessi (2021) reported that electricity accessibility has a negligible environmental effect while access to clean fuels degrades the environment. Similarly, Khan et al (2020) verified the criticality of electricity access and the advancement of the financial sector in protecting Pakistan's environment between 1990 and 2015 and discovered that electricity access and financial advancement both cause environmental damage. In a group of 35 SSA economies between 1995 and 2016, Hishan et al (2019) conclude that electricity access and clean technologies for cooking positively influence carbon emissions

Some studies have focused on the implications of electricity consumption (captured by per capita electricity usage) on the environment. Focusing on China between 1970 and 2014, Akadiri et al (2020) established that electricity consumption deteriorates the environment. In a related study in Tunisia between 1971 and 2013, Kwakwa (2020) concluded that electricity consumption damages the environment. Likewise, in Ghana, between 1971 and 2014, Kwakwa

(2021) discovered that electricity consumption has a negligible influence on environmental pollution whereas a power crisis degrades the environment. Similarly, Keshavarzian and Tabatabaienasab(2022) employed ARDL in Iran between 1970 and 2018 and confirmed that the nation's environment is deteriorated by electricity consumption. Relatedly, Kahouli et al (2022) confirmed that electricity consumption increases environmental damage in Saudi Arabia

Some scholars have assessed the nexus between environmental quality and electricity production from clean energy sources. These studies documented that electricity production from sustainable energy sources promotes environmental preservation. Voumik et al (2022) assessed the influence of electricity production on environmental pollution in selected ASEAN economies from 1971 to 2020. Using GMM, the study highlighted that electricity generated from hydroelectric sources minimizes environmental pollution while electricity generated from natural gas and coal has the opposite effect. Focusing on Malaysia, Bello et al (2018) reported that hydroelectricity lessens the deterioration of the environment thereby promoting environmental sustainability. Likewise, in Italy, Bento and Moutinho (2016) reported that power generation from renewable sources lowers environmental pollution

The second literature strand considers the role of debt stock in safeguarding the environment. The theoretical arguments between debt and economic outcomes are ambiguous. For instance, classical economists aver that public borrowing stifles economic outcomes by lessening both the budgeting process's financial discipline and the capacity of the private sector to access credits (Bal and Rath 2018). Contrarily, according to Keynesian doctrine, the government should increase borrowing to attain higher economic outcomes. Put differently, the theory asserts that public spending supported by debt has a fiscal multiplier influence on economic outcomes (Hilton 2021). The Equivalence view, pioneered by David Ricardo, contends that the influence of government borrowing on the economic outcome is neutral (Olaoye 2022). However, according to the debt overhang theory, if a country's future debt obligations exceed its capacity to pay them back, the costs of predicted debt servicing will deter additional investment, thereby dragging economic outcomes (Bal and Rath, 2018). On the other hand, prior studies that looked at how public debt affects the environment also produced conflicting findings. For instance, in a group of the Organization of Islamic Cooperation (OIC) nations between 1996 and 2018, Farooq et al (2023) reported a positive and significant influence of public borrowing on ecological performance. In another related study, Zeraibi et al (2023) disclosed that environmental degradation is reduced by public borrowing in emerging nations

Sadiq et al (2022) appraised the criticality of external debt, nuclear energy and financial development in advancing both environmental conditions and human welfare in emerging nations between 1990 and 2019. The authors revealed that environmental sustainability is aided by external debt and nuclear energy, whereas financial globalization drives ecological decline.

Likewise, in 78 emerging economies from 1990 to 2015, Carrera and Vega (2022) established that environmental deterioration is accelerated by external debt. In Ghana, Alhassan and Kwakwa (2022) concluded that public debt initially causes a decrease in environmental damage but once the debt has doubled, environmental pollution increases. In a similar inquiry for China, Qi et al (2022) discovered that public borrowing encourages considerable reductions in urban emissions.Likewise, in a study of 50 nations (covering both emerging and advanced nations) between 2001 and 2009; Zhao and Liu (2022) documented the diverse influence of debt on emissions depending on how debt was quantified. For example, total debt and private debt aggravate and reduce environmental pollution respectively while debt structure lowers and increases pollution in advanced and emerging nations respectively. Focusing on four African economies between 1970 and 2018, Akam et al (2021a) appraised the environmental sustainability effect of foreign debt and disclosed that environmental preservation is not significantly impacted by foreign debt. In a related study of 33 economies with high debt levels, Akam et al (2021b) discovered that foreign debt does not considerably contribute to environmental damage. Bese et al (2021a) appraised the effect of external debt on India's ecological damage between 1971 and 2012 and revealed that rising foreign debt worsens environmental sustainability. The debt-environment nexus in China between 1978 and 2014 was examined by Bese et al. (2021b) using the linear and nonlinear ARDL models and reported that foreign debt positively and significantlyinfluences environmental pollution.Relatedly in Turkey, Katircioglu and Celebi (2018) disclosed that ecological deterioration was not considerably impacted by external debt.

3. Methodology

3.1. Empirical Model

To achieve the first goal, we provide details about our baseline linear models, which express environmental sustainability as a function of public debt and electricity access, and some control variables following the modelling strategy of prior studies like Bello et al (2018) and Ndubuisi et al (2022).

This research proposes a dynamic panel model in the shape of

$$lnES_{it}^{co2,ecol} = \alpha_i + \beta X_{it}^{pud,elect} + \gamma lnZ_{it} + \varphi_t' + \varepsilon_{it} \quad (1)$$

$lnES_{it}^{co2,ecol}$=natural logarithm of environmental sustainability proxied by CO_2 emission in metric tons per capitaand Ecological footprint. $lnX_{it}^{pud,elect}$=vector of the natural logarithm of public debt and electricity access. γlnZ_{it}=vector of control variables in natural logarithms (GDP per capital, financial development, urbanization and renewable energy).β, γ are parameters to be estimated;φ_t'=is the time dummies that control for several financial and economic shocks; ε_{it}= stochastic error term; the parameters estimate and associated a priori predictions is $\beta < 0, and\, \gamma < 0. i$ in time t. We include an interaction term (PUBELECT) in Eq. 1 to capture the second objective, and the specification becomes:

$$lnES_{it}^{co2,ecol} = \alpha_i + \pi X_{it}^{pud,elect} + \vartheta Y_{it}^{\text{pubelect}} + \rho lnZ_{it} + \omega_t' + \mu_{it} \qquad (2)$$

Where π, ϑ, ρ = parameter to be estimated; ω_t'=time dummies; Y_{it}= interaction term (PUBELECT); μ_{it}=error term. From Eq [2], ϑ offers two econometric insights. i) the coefficient sign reveals whether public debt or electricity access has a major moderating effect on environmental sustainability.Specifically, if the interplay of the two variablesmitigates or aggravates environmental sustainabilityii) the magnitude of the coefficients generated through their interplay may maintain or alter the effect of their standalone on environmental sustainability which is derived as:

$$\frac{\partial ES}{\partial X} = \pi + \vartheta Y \qquad (3)$$

Following Ndubuisi et al. (2022);Alola, et al (2023) the threshold of public debt and electricity access is expressed thus

$$ES = \frac{\pi}{\vartheta} \qquad (4)$$

3.2. Estimation Approach

Building the studies by Pesaran (2004; 2015), we first applied cross-sectional dependence (CSD). Cross-sectional dependence (CSD) in this context refers to the presence of interdependencies or correlations among observations across different units in a dataset, typically in the context of panel data analysis. It implies that the observations of one unit are not independent of those of other units, violating the assumption of independence commonly made in standard statistical analyses (Baltagi&Pirotte 2010; Basak& Das 2018). CSD can arise due to various factors, such as common unobserved factors, spatial or temporal spillover effects, or network interconnections among units. Researchers often choose to investigate cross-sectional dependence to account for the potential bias and inefficiency that may occur when the assumption of independence is violated (Sarafidis&Wansbeek 2012; Baltagi&Pirotte 2010; Basak& Das 2018). By incorporating appropriate techniques, such as IV-GMM or dynamic panel data models, we can capture and account for the interdependencies across units, leading to more accurate and robust empirical results in this research.The panel model residuals under the null hypothesis of the CSD test are presented as follows in this estimation:$H_o: \hat{p}_{ik} = corr(\epsilon_{it}\epsilon_{kt}) = 0 \forall i \neq k$, while the Pesaran (2004; 2015) CSD test is as follows:

$$CSD = \sqrt{\frac{2T}{n(n-1)}\left(\sum_{i=1}^{n-1}\sum_{k=i+1}^{n}\hat{p}_{ik}\right)} \sim n(0,1)i,k \qquad (5)$$

$CSD = (1,2,\dots\dots\dots\dots\dots\dots\dots\dots\dots N)$

$T = (2005,\dots\dots\dots\dots\dots\dots\dots\dots 2018)$, $n$is the total number of cross-sections or 39 SSA countries. $\hat{p}_{ik}$ in Eq. 5 presents the ADF evaluation in relation to the cross-sectional pairwise connection.

Second, test for the presence of slope heterogeneity. Slope heterogeneity refers to the situation where the relationship between two variables varies across different groups or subpopulations (Pesaran& Yamagata 2008). It implies that the slope or the magnitude of the effect of one variable on another is not constant but differs across different levels or characteristics of the population. We leverage this to investigate slope heterogeneity and gain more insights into the varying impacts of the variable of interest across different groups. By identifying and analyzing the differences in slopes, we unravelled the heterogeneous effects, identify subgroup-specific patterns, and tailor interventions or policies accordingly.The equation is as follows:

$$\hat{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\bar{S} - k\right), \hat{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\bar{S} - 2k\right) \qquad (6)$$

Along with the homogeneous and heterogeneous slope coefficients, the delta and modified delta represents the null and alternative hypotheses.

Third, the instrumental Variable Generalized Method of Moments (IV-GMM) was applied as the main estimation technique. The IV-GMM is a statistical technique that econometric scholars employ to handle endogeneity issues and determine causality between variables. It merges the benefits of instrumental variables (IV) and the generalized method of moments

(GMM). IV-GMM research is a prevalent choice when exploring causal effects in situations where traditional regression models may give biased or inconsistent estimates due to omitted variables or simultaneity. By applying instrumental variables[1] to handle endogeneity, IV-GMM delivers a robust framework to estimate causal effects by applying moment conditions. This technique enables scholars to surmount challenges associated with omitted variable bias, measurement error, and other forms of endogeneity, making it a potent tool for investigating causal relationships in diverse economic and social contexts (Baum, et al., 2003).The Kleibergen-Paap Wald F-statistic, Hansen test statistics and Kleibergen-Paap Lagrange Multiplier are employed in this study to assess the validity and reliability of the IV-GMM outcomes. Several recent studies have used the IV-GMM estimator (Acheampong et al. 2022; Acheampong et al. 2023; Dimnwobi et al. 2022b).

For robustness purposes, we applied the Lewbel (2012) 2SLS method to assess the consistency of the IV-GMM results. This technique is essential when reliable external instruments are not accessible or are thought to be possibly unreliable. This approach takes advantage of data heteroskedasticity to build internal instruments that are utilized in dealing with endogeneity. The Lewbel 2SLS technique has the advantage of not requiring the fulfilment of conventional exclusion requirements (Lewbel 2012). This approach has been used extensively in recent applied research (Domguia et al. 2022; Essel-Gaisey and Chiang, 2022; Martey 2022).

3.3. Data

This inquiryutilizes annual data from 39 SSA nations (See Appendix 1) between 2005 and 2018. The periodicity is predicated on data availability.We employed CO_2 emissions captured in metric tons per capita and ECOL captured as the global hectares (Gha) per person as the dependent variables. These two variables were uniquely employed to accurately capture multiple aspects of environmental deterioration. For example, CO_2 is thought to be the main cause of the rising levels of greenhouse gases that harm the ecosystem and exacerbate climate change and global warming. Furthermore, CO_2 plays an important role in ongoing discussions about reducing climate change, protecting the environment, and promoting sustainable development (Ehigiamusoe et al. 2019; Lin and Li 2019). Some studies, however, argued that

[1] The rationale for using lags of the independent variables as instrumental variables in IV-GMM lies in the aim to address endogeneity concerns arising from simultaneous relationships and reverse causality. By incorporating lagged values as instruments, IV-GMM leverages the temporal nature of the data to offer a solution (Baum, et al., 2003). The notion is that lagged independent variables serve as valid instruments, as they exhibit correlation with the current values of the independent variables while remaining unrelated to the error term (Acheampong et al. 2022; Acheampong et al. 2023; Dimnwobi et al. 2022b; Voumik, et al 2022) This correlation enables the instrumental variables to capture the exogenous variation in the independent variables, effectively mitigating the endogeneity issue (Muoneke, et al 2023). Employing lagged values as instruments assumes that the current independent variables are influenced by their past values, but not by contemporaneous errors.

CO_2 does not encompass all facets of environmental damage (Dimnwobi et al. 2021; Dimnwobi et al. 2022b;Ehigiamusoe et al. 2022;Fakher et al. 2023). As a result, we complement CO_2 with ECOL which is regarded as a reliable method for assessing the environmental pressures placed on the ecosystem by human actions. Because human actions influence the natural atmosphere and impair the quality of the water and land, it has been suggested that ECOL is a broad-based indicator for environmental deterioration (Ehigiamusoe et al. 2022). Electricity access (ELECT) is access to electricity as a ratio of the population while Public debt (PUD) is as a ratioto the GDP. Following previous related studies (Alhassan andKwakwa, 2022; Dimnwobi et al. 2021; Ehigiamusoe and Dogan 2022; Ehigiamusoe et al. 2022;Fakher et al. 2023), four control variables were adopted namely urbanization (URB), per capita economic growth (GDP), renewable energy consumption (REN) and financial development (FID). GDP is measured in constant 2010 USD; FID is captured as domestic credit to the private sector as a ratio of GDP, URB is urban population as a ratio to the overall population and REN is the percentage of overall final energy consumption. Except for PUD and ECOL collected from International Monetary Fund and Global Footprint Network Databases respectively, every other variable was derived from the World Development Indicators database.

4. Empirical Results

4.1. Descriptive Statistics

The top part of Table 1 shows information about how the variables have changed over time. In the bottom part, you can find the results of correlation analyses. This implies that the study's variables are skewed to the right.These results imply that the distributions of the variables are not symmetric but asymmetric. The mean values and standard deviation are also compared side by side in the same manner.This makes it easier to determine whether or not the mean depicts the actual data accurately.The fact that the actual data exhibits no discernible variation from the mean demonstrates that the mean values are an accurate representation of real-world data. The average public debt and electricity access in SSA are weak, as shown by the maximum and minimum values of the metrics (232.093 and 0.474 and 99.690 and 2.660) respectively. In sum, SSA's public debt and electricity access economic contribution towards sustainability is moving slowly in comparison to other nations. All the variables are leptokurtic (>3) except electricity access, renewable energy and urbanization which are platykurtic in data distribution. Regardless of the sign of the correlation, all predictors have a statistically significant connection with the outcome variables. The coefficient sign of public debt and renewable energy is negative, while electricity access and other variables are positive. Likewise, because all correlation statistics are lower than 0.75, the results of the correlation study do not suggest multicollinearity among the covariate.

Table 1: Descriptive Statistics and Correlation

	ECOL	CO2	PUD	GDP	ELECT	REN	URB	FID
Mean	1.445	0.975	45.500	2388.187	39.221	67.278	40.047	12.816
Median	1.215	0.280	39.449	1034.405	35.413	77.750	39.287	10.824
Maximum	3.820	11.944	232.093	20532.980	99.690	97.420	89.370	81.324
Minimum	0.620	0.020	0.474	210.804	2.660	3.540	9.375	5.210
Std. Dev.	0.656	1.926	30.268	3277.866	24.698	25.214	16.707	5.201
Skewness	1.576	3.463	1.857	2.662	0.603	-1.043	0.526	2.095
Kurtosis	5.055	15.371	8.538	11.156	2.476	2.968	2.947	3.926
Jarque-Bera	322.066	4572.811	1011.361	2158.259	39.291	98.950	25.204	148.542
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CORRELATION							
ECOL	1.000							
CO2	0.714	1.000						
PUD	-0.135	-0.191	1.000					
GDP	0.727	0.888	-0.244	1.000				
ELECT	0.613	0.554	-0.029	0.635	1.000			
REN	-0.716	-0.679	0.051	-0.692	-0.686	1.000		
URB	0.427	0.537	0.025	0.597	0.650	-0.524	1.000	
FID	0.399	0.573	0.031	0.603	0.467	0.384	0.414	1.000

Source: Authors Compilation

4.2. Preliminary Results

First, we present the output of the CSD test. As shown in Table 2, the test statistic values produced from each variable reject the null hypothesis of weak CSD at the 1% level and confirm the presence of strong CSD.

Table 2: Cross-section dependence test

Variable	CD-test	p-value	average joint T	mean ρ	mean abs(ρ)
ECOL	2.619	0.009	14	0.03	0.4
CO2	29.167	0.000	14	0.29	0.54
PUD	26.042	0.000	14	0.26	0.53
GDP	46.412	0.000	14	0.46	0.66
ELECT	78.92	0.000	14	0.77	0.77
REN	39.592	0.000	14	0.39	0.54
FID	38.570	0.000	14	0.22	0.47
URB	78.152	0.000	14	0.77	0.96
GDPSQ	46.388	0.000	14	0.46	0.66
PUBELEC	43.246	0.000	14	0.42	0.64

Notes: Under the null hypothesis of cross-section independence, CD ~ N(0,1); P-values close to zero indicate data are correlated across panel groups. Source: Authors Compilation. *p <0.10, **p <0.05, ***p <0.01.

Second, we subjected our study to slope homogeneity tests as shown in Table 3 using Pesaran and Yamagata's (2008) Delta tilde($\tilde{\Delta}$) and adjusted delta($\tilde{\Delta}_{Adj}$) tests for slope homogeneity. The null hypotheses were disproved at the 1% level of significance, demonstrating that slope coefficients are present and homogeneous.

Table 3:Pesaran and Yamagata (2008) slope heterogeneity test

Model Specification	Delta tilde	p-value	Adjusted delta tilde	P-value
CO2-pud	8.284	0.000	12.653	0.000
ECOL-pud	6.691	0.000	10.22	0.000
CO2-pud-interaction	6.164	0.000	10.315	0.000
ECOL-pud-interaction	5.156	0.000	8.625	0.000
CO2-elect	7.686	0.000	11.74	0.000
ECOL-elect	6.451	0.000	9.854	0.000
CO2-elect-interaction	5.961	0.000	9.975	0.000
ECOL-elect-interaction	5.331	0.000	8.921	0.000

Source: Authors Compilation. *p <0.10, **p <0.05, ***p <0.01.Standard errors in (.); t-statistics in [.]

4.3. Primary Findings

In Table 4, we present the most important findings from the IV-GMM. Given that two indicators of environmental sustainability were used, the results from using carbon emission and ecological footprint are presented in columns (1) through (8), and the results from using public debt (PUD) and electricity access (ELECT) as independent variables are presented in column (1 through 4), all of which are related to the linear model of Eq. (1), column (5 through 8), are related to the non-linear model of Eq. (2) respectively. The "Net Effect" and the "Threshold of Public debt and Electricity Access" presented at the bottom right corner of Table 4 were calculated using the nonlinear model of Eq. (2), and the results from the related interaction models are displayed in columns (5) through (8).

From the linear estimates of equation 1 (see columns1 and 2), a percentage increase in the public debt (PUD) increases CO_2 emissions and ecological footprint in SSA countries by 0.102% and 0.044%. This finding is in line with theoretical expectation, particularly the classical economists who submits that public debt stifles economic outcomes and may not be effective in safeguarding the environment. This shows that SSA governments have not channelled the borrowed resources to fund environmental and clean energy projects. The necessity to expand output to offset debt may put a strain on the environment. Relatedly, Zhao and Liu (2022) contend that public borrowing may increase deforestation and hinder the development of renewable energy sources. Our study aligns with prior studies like Alhassan and Kwakwa (2022); Bese et al. (2021a); Bese et al. (2021b) and Carrera and Vega (2022). The findings also reveal that increasing access to electricity reduces CO_2 emissions and ECOL by 0.334 and 0.078%, respectively (based on columns 3 and 4). Put in another form, a rise in access to electricity generates a corresponding increase in environmental sustainability, ceteris paribus. The study confirmed that electricity access is a catalyst for protecting the SSA environment. This discovery aligns with Ansari et al (2022) and Bilgili et al (2022). For sustainable development goals to be met in SSA, regular electricity access is essential. However, when there is no access to electricity, people cannot embrace contemporary cooking methods, so they are compelled to use readily available and inexpensive dirty fuels like fossil fuels or firewood, which harm the environment. Poor electricity access for heating increases the demand for firewood, which lowers air quality (Dimnwobi et al. 2022a; Dimnwobi et al. 2022b)

The effect of GDP on CO_2 and ECOL is positive (Columns 1-8). The coefficient of linear GDP resulted in a substantial positive influence for both CO_2 and ECOL. This suggests that the initial economic boom produces more environmental damage in SSA by generating large amounts of pollution. This confirms that the recent growth trajectory in the region has been unable to protect the environment. This outcome reinforces the assumption that SSA countries have yet to show considerable achievement in safeguarding the region's environment. This justifies the demand for increased funding in emission-reduction measures, as well as improved cooperation among the nations in the region and increased efficacy of current environmental legislation. This outcome aligns with related studies in SSA such as Acheampong et al. (2019) Vural (2020),Salahuddin et al (2020) and Jian et al (2022). GDP squared has a negative relationship with CO_2 and ECOL, but it is not statistically significant (Columns 1-8). This shows that the inverted U-shaped hypothesis is not valid for this selection of sub-Saharan economies. This shows that our study did not validate the EKC predictions and this aligns with previous studies in SSA like Jebli et al. (2015), Zoundi (2017) and Inglesi-Lotz and Dogan (2018)for 24 SSA nations, 25 and 10 SSA economies respectively. The region has most likely not reached the income level required for emissions to begin to decline.The estimations show a monotonically growing linear influence, indicating a connection between rising per capita GDP and increasing levels of environmental damage in SSA. By implication, using economic policies to tackle environmental concerns in sub-Saharan economies might be ineffective and might not yield the expected economic targets.Consequently, employing economic measures to address environmental issues in SSA may be counterproductiveand may not achieve the desired environmental outcomes.

REN is negative and statistically significant, implying that increasing REN by 1% reduces CO_2 emissions and ECOL by 0.316% and 0.144%, respectively.Based on these estimates, it seems that investing in renewable energy will be a key part of addressing environmental issues in the SSA. Interestingly, this finding highlights the role of SDG target 7.2 in meeting SDG 13's climate action goal. This result shows that renewable energy is effective or a catalyst in reducing environmental damage in SSA thereby promoting environmental sustainability. This outcome agrees with Inglesi-Lotz and Dogan (2018); Vural (2020) and Salahuddin et al. (2020) for 10, 8 and 34 SSA nations respectively, Akam et al. (2021b) for highly indebted nations; Ehigiamusoeand Dogan (2022) for 26 economies, Jian et al (2022) for 16 SSA economies and Fakher et al (2023) for 13 selected economies. This outcome shows that environmental sustainability is enhanced as people embrace clean energy sources like wind power, hydropower and solar power which are eco-friendly relative to traditional sources of energy which pollute the environment. This discovery has policy implications in that policies to mitigate pollution should be developed by SSAs, and they should promote the use of more renewable energy in their energy utilization mixture

In columns, (1-8) model specifications, the coefficient of FID is positive and significant. For instance, increasing financial sector development by 1% has been shown to trigger CO_2 emissions and ecological footprint by an average of 0.122-0.028% ceteris paribus, suggesting that financial development cannot aid environmental sustainability concerns initiatives in SSA due to its underdeveloped nature. This demonstrates that financial institutions in SSA nations do not provide firms with financial inducements to participate in environmentally friendly initiatives and encourage them to embrace cutting-edge technology that lessens environmental deterioration. Put differently, priorities are not given to firms by the financial institutions in SSA to invest in ecologically friendly projects that boost energy efficiency and cut pollution. Our result on the inability of the financial sector to protect the SSA environment aligns with Ehigiamusoe and Lean (2019); Nathaniel et al (2020) and Fakher et al (2021) while contradicting Acheampong et al (2020), Kirikkaleli and Adebayo (2020); Musa et al (2021); Habiba and Xinbang (2022) and Liu et al (2022). The environmental effect of urbanization (URB) is positive and statistically significant and varies between 0.025–0.497 across the column (1-8) estimated specifications. For instance, in column 1, there is a 0.497% rise in environmental sustainability concerns (CO_2 emission) for every one-unit increase in urbanization. The outcome confirms that urbanization is ineffective in protecting the environment which is in tune with recent submissions like Alhassan and Kwakwa (2022); Habiba and Xinbang (2022) and Jian et al (2022) while disagreeing with Dimnwobi et al. (2021) and Tarazkar et al. (2020). Traffic and congestion rise as urbanization rises, which in turn leads to increased energy use and, ultimately, higher pollution. Similarly, as argued by Iheonu et al. (2021), the requisite infrastructure development has not kept up with SSA's urbanization, leading to improper waste management which harms the environment.

Table 4: IV-GMM Results

VARIABLES	CO2 1	ECOL 2	CO2 3	ECOL 4	CO2-INT 5	ECOL-INT 6	CO2-INT 7	ECOL-INT 8
PUD	0.102***	0.044**			0.095***	0.143***		
	(0.035)	(0.019)			(0.064)	(0.045)		
	[2.942]	[2.290]			[3.481]	[3.193]		
ELECT			-0.334***	-0.078***			-0.305***	-0.121***
			(0.044)	(0.030)			(0.055)	(0.037)
			[7.645]	[-2.610]			[-5.567]	[-3.272]
GDP	1.286***	0.16***	0.599**	0.064**	0.760***	0.103***	0.567**	0.016**
	(0.270)	(0.154)	(0.251)	(0.175)	(0.279)	(0.181)	(0.242)	(0.168)
	[4.764]	[3.033]	[2.390]	[2.363]	[2.718]	[2.569]	[2.343]	[2.093]
GDPSQ	-0.056	-0.059	-0.027	-0.025	-0.017	-0.022	-0.034	-0.035
	(0.040)	(0.024)	(0.037)	(0.026)	(0.041)	(0.027)	(0.035)	(0.025)
	[-1.394]	[-1.483]	[-0.716]	[-0.934]	[-0.412]	[-0.837]	[-0.954]	[-1.403]
REN	-0.316***	-0.144***	-0.305***	-0.156***	-0.302***	-0.151***	-0.302***	-0.151***
	(0.040)	(0.033)	(0.036)	(0.035)	(0.039)	(0.034)	(0.036)	(0.034)
	[-7.914]	[-4.335]	[-8.454]	[-4.438]	[-7.837]	[-4.451]	[-8.348]	[-4.460]
FID	0.122***	0.028***	0.090***	0.054***	0.082***	0.048**	0.082***	0.042**
	(0.032)	(0.020)	(0.029)	(0.018)	(0.031)	(0.020)	(0.030)	(0.020)
	[3.847]	[3.390]	[3.129]	[2.895]	[2.676]	[2.412]	[2.762]	[2.124]
URB	0.497***	0.068**	0.373***	0.008**	0.402***	0.021**	0.361***	0.025*
	(0.055)	(0.034)	(0.058)	(0.038)	(0.059)	(0.038)	(0.060)	(1.538)
	[9.102]	[2.016]	[6.483]	[2.209]	[6.856]	[2.543]	[6.057]	[0.652]
PUBELEC (INTERACTION)					-0.119***	-0.059***	0.017**	0.025**
					(0.029)	(0.021)	(0.019)	(0.011)
					[-4.047]	[-2.769]	[2.899]	[2.268]
Net effect					-5.320	-2.542	0.362	0.860
Threshold					0.798	2.424	6.176	4.840
Turning point					2.222	11.288	481.290	126.469
Constant	-4.436***	0.299	-3.244***	0.024	-3.315***	-0.261	-3.189***	0.104
	(0.410)	(0.245)	(0.360)	(0.279)	(0.470)	(0.336)	(0.348)	(0.272)
	[-10.809]	[1.220]	[-9.023]	[0.085]	[-7.053]	[-0.775]	[-9.176]	[0.381]
Diagnostic Test								
Kleibergen-Paap LM statistic	4.793	3.807	5.849	5.863	5.821	5.835	5.877	5.891
P-val	0.222	0.401	0.238	0.517	0.68	0.959	0.796	0.789
Cragg-Donald Wald F statistic	325.546	118.372	843.15	160.324	208.802	525.976	177.498	349.111
Kleibergen-Paap Wald F statistic	46.722	88.129	142.35	63.757	99.536	120.943	85.164	106.571
Hansen J statistic	0.274	0.413	0.931	0.069	0.652	0.791	0.208	0.347
P-val	0.507	0.102	0.113	0.518	0.303	0.708	0.923	0.723
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

VARIABLES	CO2 1	ECOL 2	CO2 3	ECOL 4	CO2-INT 5	ECOL-INT 6	CO2-INT 7	ECOL-INT 8
Observations	546	546	546	546	546	546	546	546
R-squared	0.918	0.586	0.924	0.589	0.922	0.593	0.925	0.592

Source: Authors Computation. *p <0.10, **p <0.05, ***p <0.01.Standard errors in (.); t-statistics in [.]

Given the criticality of public debt and access to electricity in the SSA, we should be interested in how to reduce the increasing cost of environmental concern in the continent arising either through public debt burden or high energy demand. As noted by Alhassan and Kwakwa (2022), one of the key probable approaches to mitigating this harm to the environment in SSA is to ensure access to modern energy and to maintain optimal debt stock. Consequently, we introduced the access to electricity variable and its interaction with the public debt in Columns (5)-(6). Similarly, we introduced the public debt variable and its interaction with access to electricity in Columns (7)-(8). The results from columns 5-6 of Table 4 indicate that the unconditional public debt and electricity access impact positively and negatively significantly on environmental sustainability in SSA respectively.

On this note, our estimates have indicated that public debt drags environmental sustainability in SSA while access to electricity improves it. Hence, the enlisted two (2) important concerns in the study are: (i) Can access to electricity moderate the negative impact of public debt on environmental sustainability in SSA? (ii) Can public debt drag the impact of access to electricity on environmental sustainability in SSA? To answer these questions, we must consider the net effect of the interplay between public debt and access to electricity to influence environmental sustainability in SSA. We find that the unconditional effect of public debt and access to electricity are positive and negative (0.095 to 0.143) and (-0.121 to -0.305) while the marginal effect through the interactive interplay varies between -0.119 to 0.025 across columns 5-8 estimated model specifications and all are statistically significant. If we take, for example, Column (5) we computed the net effect of public debt and access to electricity using Eq. (3) as:

$$\frac{\partial oc2-int}{\partial pud} = 0.095 - 0.119elect \tag{7}$$

$$\frac{\partial co2-int}{\partial elect} = -0.305 + 0.017pud \tag{8}$$

As a result, the net effect of public debt on environmental sustainability ranges from −0.5.320 to -2.542 at an average level of access to electricity whereas the net effect of electricity access on environmental sustainability varies between 0.362 to 0.860 at the average level of public debt[2]. The key implications are (i) This suggests that access to electricity reduces the adverse effect of public debt on environmental sustainability in SSA (ii) Public debt considerably dampens the positive effect of access to electricity effect on environmental sustainability. This suggests that environmental concerns are aggravated by the debt burden. Accordingly, we computed the threshold level of public debt and access to electricity given that their unconditional and conditional effects have opposite signs (i.e., positive/negative). The threshold here implies the turning point at which environmental concerns are either aggravated or moderated through the interplay of public debt and access to electricity. Thus, the threshold is computed using Equation 4 and by making this Equation 3 equal to zero (Muoneke et al. 2022; Ndubuisi et al. 2022). Consequently, the threshold value is equal to $\frac{\pi}{\vartheta}$. These values are displayed in the bottom right corner of Table 4.Relying on the threshold of public debt % of GDP that varies between (2.222-11.288) in columns 5 and 6, the average ratio of public debt to GDP (45.5)[3] for SSA is above the threshold debt of 2.222-11.288% of GDP, thus increasing public debt can trigger environmental sustainability concerns via increasing CO_2 emissions and ecological footprint. Conversely, in columns 7 and 8, the average level of access to electricity (39.221) from Table 1 is below the threshold of (126.469-481.290). This implies that the current average level of modern electricity (which stands at 39.221, on average) does not provide a meaningful reduction of environmental damage through debt financing in SSA.

To evaluate the viability of the IV-GMM models, we subjected the models to four diagnostic checks.The checks include the Kleibergen-Paap LM statistic, Kleibergen-Paap Wald F statistic and Cragg-Donald Wald F statistic, all depicting that the estimates are free from redundant and invalid instruments. The stock-Wright LM test demonstrates that the coefficient on the change in the independent is equal to zero and that over-identifying constraints are valid across model specifications.The Hansen J statistic also confirms the accuracy of the estimating instruments. The R-squared, which measures variations in the endogenous variable predicted by the

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[2] Table 2 (descriptive statistics) the average level of public debt and access to electricity are 45.5 & 39.221. As a result, the net effect is calculated by substituting the average value of public debt and access to electricity into the equations below as thus:

$$\frac{\partial oc2-int}{\partial pud} = 0.095 - 0.119(39.221)$$

$$\frac{\partial co2-int}{\partial elect} = -0.305 + 0.017(45.5)$$

[3] Table 2 (descriptive statistics)

independent factors, ranges from 0.589 to 0.924, suggesting that independent variables collectively explain variation in environmental sustainability.

4.4. Robustness Check

In the robust check, we applied the 2SLS approach. Concentrating on the key factors, the findings emanating from Table 5 vis-a-vis 2SLS can be summarized as follows: (i) Public debt impacts adversely and significantly on environmental sustainability in SSA; (ii) Access to electricity impacts favourably and significantly on environmental sustainability in SSA; (iii) Access to electricity in SSA considerably reduces the harmful effects of public debt burden on environmental sustainability in the SSA resulting to negative net effect; and (iv) Public debt in SSA considerably reduces the favourable effect of electricity access on environmental sustainability in the SSA resulting to positive net effect.

Table 5: Result of robustness check using2SLS

VARIABLES	CO2 1	ECOL 2	CO2 3	ECOL 4
PUD	0.095***	0.143***		
	(0.066)	(0.043)		
	[2.949]	[3.312]		
ELECT			0.105***	-0.121***
			(0.056)	(0.037)
			[5.454]	[-3.250]
GDP	0.760***	0.103**	0.567**	0.016**
	(0.284)	(0.186)	(0.267)	(0.178)
	[2.673]	[2.554]	[2.122]	[2.088]
GDPSQ	0.017	0.022	0.034	0.035
	(0.043)	(0.028)	(0.041)	(0.027)
	[0.388]	[0.797]	[0.827]	[1.292]
REN	-0.302***	-0.151***	-0.302***	-0.151***
	(0.046)	(0.030)	(0.045)	(0.030)
	[-6.616]	[-5.072]	[-6.744]	[-5.041]
FID	0.082***	0.048**	0.082***	0.042**
	(0.028)	(0.019)	(0.028)	(0.018)
	[2.906]	[2.567]	[2.969]	[2.276]
URB	0.402***	0.021**	0.361***	0.025
	(0.056)	(0.037)	(0.054)	(0.036)
	[7.215]	[2.572]	[6.648]	[0.677]
PUBELEC (INTERACTION)	-0.119***	-0.059***	0.017**	0.025**
	(0.031)	(0.020)	(0.018)	(0.012)
	[-3.852]	[-2.938]	[2.948]	[2.090]
Constant	-3.315***	-0.261	-3.189***	0.104
	(0.464)	(0.304)	(0.388)	(0.259)
	[-7.141]	[-0.857]	[-8.220]	[0.400]
Net effect	-5.320	-2.542	0.562	0.860
Threshold	0.798	2.424	6.176	4.840
Turning point	2.222	11.288	481.290	126.469
Observations	546	546	546	546

VARIABLES	CO2 1	ECOL 2	CO2 3	ECOL 4
R-squared	0.922	0.593	0.925	0.592

Source: Authors Computation. *p <0.10, **p <0.05, ***p <0.01.Standard errors in (.); t-statistics in [.]

5. Conclusions and Policy Implications

This research represents the pioneer effort to uncover the relationship between electricity access, debt stock and environmental sustainability in SSA between 2005 and 2018. We focused on SSA because the region has the globe's lowest rate of electricity access as well as increasing debt levels while also being extremely vulnerable to climate risk. We evaluated this linkage using the IV-GMM which is renowned for generating reliable results. The empirical conclusions of the study are robust to heteroscedasticity, endogeneity and CSD which can cause panel estimates to be biased, inefficient and inconsistent. The study's key findings are as follows: (i) Public debt undermines environmental sustainability in SSA (ii) Electricity access is a catalyst for protecting the SSA environment (iii) Renewable energy aided in the reduction of environmental pollution in SSA (iv) Financial advancement and urbanization are ineffective in protecting the SSA's environment (v) GDP substantially led to the deterioration of the environmentwhile GDP square is negatively associated with environmental pollution but not statistically significant (vi) Electricity access decreases the negative impact of public borrowing on environmental sustainability in SSA while public debt considerably dampens the positive effect of access to electricity effect on environmental sustainability

The study's findings have significant policy ramifications. First, the study established that public debt deteriorates the environment in SSA. We suggest that the relevant authorities and decision-makers should make sure that borrowed money is directed towards clean energy infrastructures. SSA countries should make use of clean energy initiatives like the recent "Facility for Energy Inclusion" (FEI) program from the African Development Bank, which provides a $500 million debt-financing instrument for small-scale alternative energy projects and off-grid alternatives. Given the uncertain global macroeconomic outlook following the post-COVID recovery efforts, SSA economies must be more innovative in how they manage the available fiscal space to ensure macroeconomic stability. In addition, to fund environmental sustainability projects, the decision-makers in the region need to prioritize public expenditure decisions free from corruption to prevent a debt crisis that could jeopardize the region's development. The borrowed fund could also be deployed as inducements for firms in the region to embrace sustainable production.

Second, the study found that expanding access to electricity promotes environmental sustainability. Therefore, policymakers in the region should strengthen further investment in electricity infrastructures, especially in rural regions to deepen accessibility of contemporary, inexpensive and effective energy. The extension of power coverage in rural regions must be supplemented with initiatives that give free or low-cost electrical appliances for household tasks. Third, expectedly the study discovered that the utilization of renewable energy promotes environmental sustainability in SSA. Hence, the decision-makers in SSA nations should promote the usage of renewable energies by providing inducements and subsidies. Research institutions and entrepreneurs can help to create and deploy renewable energy solutions. Although using non-renewable energy could be less expensive, it has negative consequences on the environment, and regrettably, SSA nations are more affected relative to other regions of the world.

Fourth, GDP is a significant ecological damage driver in SSA. This finding suggests that the economic activities of SSA have led to the rise of environmental pollution. Consequently, if decision-makers do not introduce energy-efficient solutions and clean energy sources, they will be unable to achieve both economic expansion and an environmentally sustainable economy. Hence, we advise SSA and regional authorities that increasing economic advancement should be accompanied by ecologically sustainable measures to offset the environmental pollution associated with economic progress. Fifth, the study established that increasing urbanization in SSA put strains on the region's environment. This study suggests that policymakers prioritize rural development to reduce rural-urban mobility. Sustainable urbanization should be promoted because it could help to lessen the detrimental environmental effect of urbanization. To promote environmental quality, a sustainable urban design that integrates environmentally friendly behaviours, green areas, and cutting-edge technologies into urban settings is needed. Sixth, the study uncovered that financial advancement triggers SSA's environmental pollution. This implies that financial institutions do not have any environmentally friendly practices, which leads to excessive environmental pollution. Policymakers, as well as the relevant authorities, should incentivize carbon-intensive firms to enhance their environmental consciousness while also extending more credit to low-carbon businesses. Additionally, stringent oversight of businesses that access credit from these financial institutions might increase the effectiveness of the region's climate change policies.

Finally, this research can be expanded in the future using data from different developing economies and different econometric strategies to further understand the influence of electricity access, debt and environmental quality. Additional studies can look into how other variables, like institutional factors and income inequality, influence the nexus between electricity access, debt and environmental quality

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Appendix 1 (Sample covered): Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo Dem. Rep, Congo Rep, Cote d'Ivoire, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe