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Energising Environmental Sustainability in Sub-Saharan Africa: the role of Governance Quality in Mitigating the Environmental Impact of Energy Poverty

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Energising Environmental Sustainability in Sub-Saharan Africa: the role of Governance Quality in Mitigating the Environmental Impact of Energy Poverty

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Abstract

The Sub-Saharan Africa region is disproportionately affected by energy poverty and is considered highly vulnerable to the impacts of climate change. Therefore, addressing the pressing challenges of energy poverty and promoting environmental sustainability in this region is of paramount importance. Consequently, this study appraises the relationship between energy poverty and ecological preservation in Sub-Saharan Africa from 2005 to 2020, using government effectiveness and regulatory quality as moderating variables. A combination of energy poverty indicators and an index of energy poverty computed via the principal component analysis method were applied to identify the link between energy poverty and ecological sustainability. The instrumental variable generalized method of moment technique was applied to address the likelihood of endogeneity issues, and the Driscoll-Kraay approach was employed to check the consistency of the instrumental variable generalized method of moment method. Key findings indicate that energy poverty expands the ecological footprint in Sub-Saharan Africa, leading to ecological deterioration, while the interaction with government effectiveness and regulatory quality further deteriorates the environment. Subsequently, the study provides several recommendations to mitigate the influence of energy poverty on the environment.

Keywords: Energy Poverty, Environmental Sustainability, Government Effectiveness, Regulatory Quality, Sub-Saharan Africa

1. Introduction

Because of the significance of its consequences for global warming and climate change, environmental sustainability is possibly the most important of the three pillars of sustainable development (Bello et al., 2022; Dimnwobi et al., 2022a). Eight of the United Nations' 17 Sustainable Development Goals (SDGs) are related to the environment, either directly (goal 6 - sanitation and clean water, goal 13 - climate action, goal 14 - life below the water, and goal 15 on life on land) or indirectly (goals 7 on clean and affordable energy, 9 on industry, innovation, and infrastructure, 11 on sustainable cities and communities, and 12 on responsible consumption and production). (United Nations Development Programme, 2015). As a result, issues related to comprehending and regulating ecological trends and patterns are essential to achieving sustainable development goals.

Despite being common in the literature, utilizing carbon dioxide (CO2) emissions as a measure of environmental sustainability may not be sufficient (Jahanger et al., 2023a; Jahanger et al., 2023b). The utilization of ecological footprint (EF) has grown in significance as a more thorough indicator of how human activity affects the environment. The EF measures how much strain the human population is putting on the planet's ecosystem and natural resources. It is computed as the amount of land and water needed, in terms of both production and absorption, to meet human needs (Dimnwobi et al., 2021). The Global Footprint Network considers EF as a vital measurement technique in the context of sustainable development because it offers a more comprehensive picture of how human actions affect the environment (Jahanger et al., 2023c)

In light of widespread concerns regarding the influence of present and future climate change, the effects of energy poverty (EP) on ecological sustainability have not been given adequate research attention. EP is described as insufficient energy consumption to meet fundamental human necessities (Gonzalez-Eguino, 2015). As noted by Dimnwobi et al. (2022b) and Dimnwobi et al. (2022c), it is explained as inadequate access to clean fuels and a heavy dependence on dirty fuels with high pollutant characteristics. There are several channels through which EP influences ecological quality. For instance, EP results in a dependence on outdated and inefficient energy sources like solid fuels to meet domestic needs (Ansari et al., 2022). These fuels are inefficiently burned, resulting in significant indoor and outdoor air pollution, which exacerbates respiratory illnesses and degrades the ecosystem. Access to electricity and contemporary energy services is restricted in areas experiencing EP (Dimnwobi et al. 2022c). The inadequate access to reliable and reasonably priced grid-based electricity often resort to the use of diesel generators, kerosene lamps, and other polluting sources to meet energy needs. These sources generate pollutants like greenhouse gases, particulate particles, and others that worsen outdoor air pollution (Bilgili et al., 2022; Okere et al., 2023). Lastly, biomass is frequently utilized as the main fuel for cooking and heating in areas that lack access to electricity. However, excessive biomass extraction can cause biodiversity loss, deforestation, soil erosion, and ecosystem disruption resulting in the deterioration of the environment (Yahong et al., 2023)

Moreso, the criticality of governance quality in enhancing environmental performance cannot be overstated. Effective governance encourages robust procedures which aid the development of plans that put pressure on stakeholders, governments, and businesses to solve ecological contamination. Additionally, the quality of governance is essential for enhancing ecological conditions and protection strategies by upholding the rule of law and ethical behaviour (Zhang & Zhou, 2016; Ni et al., 2022). Two hypotheses are commonly connected with the governance-environmental nexus. The first is the "race to the bottom" hypothesis, which highlights that domestic governments consciously lower their ecological rules to increase their economic advantage by attracting more foreign aid and investments. The "race to the top" idea, however, contends that decision-makers in developing economies tighten their environmental laws to entice more investments in eco-friendly energy and expand their economies (Zhang & Zhou, 2016; Ni et al., 2022).

The Sub-Saharan Africa (SSA) region has been the most severely impacted by climate change, although being the least responsible for it (Edziah et al., 2022; Shobande & Asongu, 2023). CO_2 emissions have consistently increased in SSA, with negative consequences. For example, in 1990, SSA's CO_2 emissions were roughly 402,373kt before skyrocketing to 823,770kt in 2019. The same period witnessed a considerable reduction in CO_2 emissions in Europe and Central Asia (World Bank, 2020). Despite worldwide attempts to protect the ecological reserve, SSA is projected to endure a severe ecological deficit (Edziah et al., 2022). Indeed, Steckel et al. (2020) discovered that the SSA emissions growth rate was among the highest in the world between 2005 and 2015. Calvin et al. (2016) predict that by 2100, Africa might contribute between 5-20% of the world's carbon dioxide emissions, while SSA could contribute between 4% and 10%. According to Leimbach et al. (2018), SSA carbon dioxide emissions will rise by 50% by 2050. These expected trends are extremely concerning, given that SSA nations are particularly vulnerable to climate change because they rely on natural resources for food and energy (Nchofoung & Asongu, 2022; Shobande & Asongu, 2022). Due to the expected increases in carbon dioxide emissions, the economies of SSA nations, where many are already poor, are likely to be more severely affected by the negative effects of climate change (Dimnwobi et al., 2021). Given this, it becomes desirable to appraise the underexplored factors that can mitigate or exacerbate ecological distortions in SSA.

Given the aforementioned issues, this research answers these research questions: (1) What effect does EP have on SSA's environmental sustainability? (2) Does governance quality moderate the influence of EP on ecological sustainability in SSA? This research influences existing literature in five aspects. First, this research appraises the influence of EP on ecological preservation by employing six contemporary inclusive proxies of EP, namely electricity access in the total, rural, and urban populations, as well as access to clean cooking facilities, renewable energy production, and utilization. Second, this study uniquely creates a six-component index of EP using the principal component analysis (PCA) to have a thorough understanding of how EP influences environmental pollution. Third, this study adds to the environmental literature by being the first of its kind to assess the moderating role of governance quality on the nexus between EP and environmental sustainability. This is crucial for the development and application of ecological interventions. Fourth, we focused on an underwhelming region (SSA) which is the EP capital of the globe as well as the region most susceptible to problems caused by climate change (Okere et al., 2023; Shobande, 2023). For instance, according to a report from the IEA (2020), between 2000 and 2019, the number of persons lacking access to grid power dropped from 1680 million to 770 million across the globe. During the same time, the number of persons without access to electricity in SSA increased from 506 million to 578 million. Similarly, roughly 905 million people are without access to clean cooking facilities in SSA (IEA, 2019). Fifth, most existing studies employ CO2 emissions to capture environmental sustainability; however, this only assesses one aspect of ecological sustainability and provides an inadequate picture of the connection between poverty and the environment. The ecological footprint (EF) is adopted in this study to better capture ecological performance since it is more inclusive and reflects strongly the environmental pressures. The EF is a composite measure of environmental integrity that contrasts the amount of available natural resources with the amount that is utilized (Bello et al., 2022; Kibria, 2023). It is a comprehensive gauge of human-induced environmental stress that correlates to ecological damage as a result of human consumption activities and the capacity of the biosphere to regenerate organically. The EF is computed by evaluating the amount of capital required to satisfy a country's resource needs and waste disposal (Kirikkaleli et al., 2023; Sun et al., 2023). The following reasons further justify the choice of EF for this study: (i) The EF considers many factors of human consumption, such as transportation, energy use, food consumption, land use, and waste generation. Compared to other environmental integrity proxies that concentrate on only one or a few factors, it offers a more comprehensive and holistic view of the effects of human activity on the environment. (ii) The biocapacity of the Earth - that is, its capacity to replenish resources and take up waste is taken into account when calculating the EF. It determines if people are residing within the ecological boundaries of the Earth by comparing human demand (EF) with the planet's capacity (biocapacity). This long-term view aids in comprehending the sustainability of human actions and their potential consequences for future generations (iii) By utilizing EF, decision-makers will be able to measure and track the environmental effects of various policies and practices. It aids in the identification of problem areas, the setting of goals for lowering resource consumption, and the development of sustainable resource management and conservation techniques. In sum, the EF is regarded as a superior proxy for environmental degradation since it gives a thorough, internationally comparable, and simply understood measure of human effect on the environment. It provides information on the viability of human endeavours and aids in the formulation of successful plans for resource management and environmental protection (Bello et al., 2022; Sun et al., 2023). Finally, by utilizing an innovative methodology and filling identified research gaps, our findings add to the burgeoning body of knowledge and equip decision-makers in the region with evidence-based interventions and policies. The study is also targeted at shaping plans to raise living standards, safeguard the environment, increase resiliency to climate change, and promote sustainable development in the region. What remains of this paper is designed as follows: The next section contains past related studies, whereas the third section expounds on the study's methodology. Section 4 displays the empirical findings, while the final segment concludes the study.

2. Literature Review

The Environmental Kuznets Curve (EKC), pioneered by Kuznets in 1955, is an extension of the Kuznets Curve hypothesis. In environmental literature, the EKC assumes an inverted U-shaped connection between economic progress and ecological damage (Sun, 1999). The EKC states that following the maxim “grow first, clean up later” economic progress results in environmental decay up until a particular threshold income level (Rock & Angel, 2007), and at this turning point, people and decision-makers start to take environmental sustainability cautiously (Azadi et al., 2011).

The literature is split into two strands for easier comprehension. While the first part concentrates on EP and environmental sustainability, the second part is on the link between governance infrastructure and ecological damage. Ansari et al (2022) appraised the macroeconomic effects of EP and established that reducing EP (that is expanding electricity access) promotes environmental quality in SSA. Likewise, Bilgili et al (2022) assessed the implications of EP reduction (proxied with electricity access) on CO2 damage in 36 Asian nations between 1997 and 2017 and the study discovered that increasing access to electricity (that is reducing EP) lesse ns CO2 damage. These studies show that reducing energy poverty by increasing access to grid-based electrification protects the environment. There are several theoretical channels through which increased electricity access can promote the environment. First, utilizing energy-efficient technology and habits is made possible by the availability of electricity. Efficient appliances, lighting, and industrial procedures contribute to minimising total electricity demand and lessening environmental stress (Dimnwobi et al., 2023). A reduction in greenhouse gas emissions and resource depletion is achieved via energy efficiency initiatives (Jahanger et al., 2023d). Second, electricity access can ease the switch from conventional biomass cooking techniques to environmentally friendly cooking methods. Electric cookers or induction stoves driven by electricity eliminate the need for solid fuels, considerably reducing indoor and outdoor air pollution (Shobande, 2023). This lessens health concerns related to indoor pollution, lowers deforestation rates, and enhances indoor air quality (Okere et al., 2023). Lastly, the expansion of electric transportation infrastructure, such as electric cars and charging stations, is made possible by the availability of power. Electric mobility minimizes dependency on fossil fuel-based transportation and lowers vehicle emissions of greenhouse gases and air pollutants, improving air quality and reducing the carbon footprint.

On the flip side, some authors document that EP damages the environment. Based on data from BRICS nations between 1989 and 2016, Hassan et al. (2022) appraised the influence of EP, glob alization, income inequality, and education on ecological damage, revealing that EP lowers envir onmental quality. In China, Zhao et al (2021) ascertained the influence of EP on environmental pollution, reporting that EP increases environmental pollution. Similarly, in China, Zhang et al (2022) uncovered the impact of EP on the building sector's carbon intensity and highlighted that EP positively impacts the sector’s carbon intensity. Relatedly, a study of 20 SSA nations between 1996-2015 by Mewamba-Chekem and Noumessi (2021) established that EP has a negligible effect on ecological impairment. Yahong et al. (2023) discovered that EP lowered environmental quality in selected Asian nations between 2006 and 2017. The reasons for these outcomes are not far-fetched. To start with, an energy deficit frequently results in a reliance on conventional, environmentally harmful energy sources, like solid fuels, and kerosene lamps among others. These sources frequently generate significant concentrations of air pollutants, such as carbon dioxide, particulate matter, and others, which worsen air quality, cause respiratory illnesses, and harm the environment (Yahong et al., 2023). Additionally, individuals and households who lack access to contemporary energy sources depend heavily on biomass for heating, cooking, and lighting. The unsustainable extraction of biomass contributes to soil erosion, deforestation, biodiversity loss, and ecosystem deterioration, all of which have significant environmental consequences.

This strand focuses on the link between governance quality and environmental pollution. While the literature is rich on these studies, this study only documents cross-country or panel studies. Theoretically, it is believed that quality institutions can facilitate the shift to sustainable development while also addressing the environmental threat. Additionally, good governance entails the creation and enforcement of stringent environmental legislation and regulations. This includes establishing precise guidelines, observing compliance, and imposing sanctions for ecological transgressions. Effective laws and regulations set up a framework for environmental protection and guarantee that enterprises, industries, and people act in a way that causes the least amount of environmental harm. Some studies have documented the criticality of quality governance in protecting the environment. For instance, for BRICS economies between 1992 and 2016, Hussain and Dogan (2021) applied the CS-ARDL to highlight that institutional quality is crucial in the fight against ecological deterioration. Gök and Sodhi (2021) probed how governance influence ecological quality in 115 nations classified in different income segments between 2000 and 2015. Using the GMM technique, improvements in governance were found to safeguard ecological protection in high-income economies. In 11 nations between 1996 and 2019, Ni et al. (2022) documented that the load capacity factor is improved by governance quality. Mesagan and

Olunkwa (2022) analyzed data from 18 African economies between 1996 and 2017 and highlighted that pollution is negatively impacted by regulatory quality.

On the other hand, weak governance could undermine environmental quality. For instance, poor governance can lead to inadequate or ineffective implementation of environmental legislation. Environmental protection measures are compromised when illegal actions, non-compliance, and environmental damage go unpunished due to inadequate monitoring, lax punishments, or a lack of compliance mechanisms. Corrupt practices, cronyism, and rent-seeking also seem to be hallmarks of weak governance. This might result in criminal operations such as illicit logging, wildlife trafficking, or the issuance of permits without conducting adequate environmental assessments. Corruption harms environmental preservation by allowing unsustainable resource extraction and weakening attempts to safeguard biodiversity and natural resources. Obobisa et al. (2022a) revealed that governance quality contributes to increased ecological impairment in 25 African economies. A similar outcome was observed by Obobisa et al. (2022b) using data from 3 African nations with the highest CO2 emissions. In selected Middle East and SSA nations, Bildirici (2022) revealed that environmental pollution is increased by governance quality. Yang et al. (2022) appraised the influence of institutional quality and income inequality on environmental pollution in 42 developing nations, and the study documented that institutional quality is not useful in protecting the environment. For selected Asian economies, Butt et al. (2023) documented a positive but insignificant influence of institutional quality on ecological damage using ARDL. Concentrating on South Asian nations from 1995 to 2020, Amin et al. (2023) established that the region's environment is harmed by institutional quality. Das and Sethi (2023) observed that environmental pollution levels in developing economies are negatively impacted by institutional quality; however, this effect is statistically negligible.

3. Methodology

3.1. Model and data description

In the first instance, we surmounted the first objective through the lens of econometric specification as domiciled in (Ehigiamusoe et al., 2022; Muoneke, et al, 2023) within the framework of the ecological footprint as a linear function of the column vector of energy poverty, the moderating value of governance quality and a row vector of control variables:

$$Y_{it} = \alpha_i + \varphi gdp_{it} + \varphi_{sq} gdpsq_{it} + \beta X_{it} + \gamma Z_{it} + \theta CTRL_{it} + \varepsilon_{it} \quad (1)$$

All variables are in natural logarithm except governance quality variables. i and t stand for countries and years, respectively. Y is the ecological footprint; the interactions between Y and GDP, as the economy progress along the development path could follow an inverted U-shaped curve according to the environmental Kuznets curve (EKC) hypothesis (Grossman & Krueger, 1991). Hence, Eq. (1) is necessary to incorporate the quadratic term of GDP per capita (GDPSQ) in the econometric equation. Accordingly, a valid inverted U-shaped curve only exists if $\varphi > 0$ and $\varphi_{sq} < 0$: X is a vector of EP: Total electricity access (EP 1), Urban electricity access (EP 2), Rural electricity access (EP 3), Clean cooking access (EP 4), Renewable energy utilization (EP 5), Renewable electricity output (EP6). Z is a vector of governance quality variables; $ctrl$ is the vector of the control variable (Urbanization), ε is noise effect, and α, β, γ θ are parameters to be estimated, and there apriori expectation depends on the level development in the selected countries.

To address the main content of this empirical exposition, the second objective is augmented in Eq. 1 with the interaction of $\beta X_{it} * \gamma Z_{it}$ as thus:

$$Y_{it} = \alpha_i + \varphi gdp_{it} + \varphi_{sq} gdpsq_{it} + \beta X_{it} + \gamma Z_{it} + \delta(X_{it} * Z_{it}) + \theta CTRL_{it} + \varepsilon_{it} \quad (2)$$

Accordingly, δ weighs if the interaction of Z_{it} on X_{it} improves or changes the influence of Z on X. If δ is positive (negative), it means that governance quality favourably (adversely) tilts the impact of EP on ecological footprint. In spirit, with (Dimnwobi, et al 2022c; Ugwu et al., 2022) we constructed an index for energy poverty called EPINDEX with a principal component and the data-generating formula is

$$\text{Epindex} = \sum_{i-1}^{n} \emptyset_i Ep_i \quad (3)$$

In Eq. (3), $\emptyset_i$ is the value of each indicator of EP at a specific time and Ep_i is the contribution of each indicator to the variation in the Epindex explained by all variables, as calculated using the principal component analysis (PCA). The six factors that serve as a proxy for EP are combined linearly to estimate the Epindex employing the individual contributions of the variables (EP) to the standardized variance of PC1 as the weights (Ep_i).

3.2. Data Description

The annual data of the 35 SSA nations (See Appendix 1) used for the study from 2005 to 2020 were obtained from the Global Footprint Network Database, the World Governance Indicator (WGI) Database and the World Development Indicators (WDI) database of the World Bank. The study however excluded some SSA nations due to data limitations across the period investigated. Following contemporary literature on EP (Apergis et al., 2021; Nguyen & Su 2021; Nguyen et al., 2021; Dimnwobi et al., 2022b; Dimnwobi et al., 2022c) we utilized six contemporary inclusive proxies of EP (Electricity access in the total, rural and urban population, clean cooking access, renewable energy utilization and renewable electricity output) to capture EP. In line with recent literature on environmental performance (Dimnwobi et al., 2021; Ehigiamusoe et al., 2022), the EF is utilized to assess environmental sustainability. Consistent with governance-environment literature (Bildirici, 2022; Evans & Mesagan, 2022; Ibrahim et al., 2022; Mesagan & Olunkwa, 2022; Ni et al. 2022, Afolabi, 2023), two primary variables are used to represent the governance infrastructure namely government effectiveness and regulatory quality. The data summary is shown in Appendix 2.

3.3. Estimation Strategy

3.3.1. Preliminary Technique

In this preliminary discussion, the stages listed below will be examined: (i) We addressed one of the most important econometric issues in cross-country by looking at the cross-sectional dependence (CSD) in the panel data set that was proposed by Pesaran (2004). This investigation is extremely important because of the profound interdependence that exists between the countries. Pesaran (2004) CSD test is used to verify the CSD under the null hypothesis of the CSD test as thus:$H_o: \hat{p}_{ik} = corr(\epsilon_{it}\epsilon_{kt}) = 0 \forall i \neq k$ while Pesaran (2004) cross-section dependent test is as thus:

$$CSD = \sqrt{\frac{2T}{n(n-1)}\left(\sum_{i=1}^{n-1}\sum_{k=i+1}^{n}\hat{p}_{ik}\right)} \sim n(0,1)\ i,k \quad (4)$$

$T = (2005, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 2020)$, n is the number of cross-sections, that is, 35 SSA nations. $\hat{p}_{ik}$ in eqt 4 introduces the ADF assessment concerning the pairwise cross-sectional connection.

(ii) We further substantiate the statistical characteristics of the data series by applying the cross-sectionally extended Im, Pesaran and Shin tests (CIPS) and cross-sectionally extended Dickey-Fuller tests (CADF) coordinated by Pesaran (2007). The equation for CIPS and CADF is:

$$\Delta Y_{it} = \omega_i + \rho_i^* Y_{i,t-1} + d_0 \bar{Y}_{t-1} + \sum_{j=0}^{p} d_{ij} \Delta \bar{Y}_{t-j} + \sum_{j=1}^{p} c_{ij} \Delta Y_{i,t-j} + \varepsilon_{it} \qquad (5)$$

The difference operator is Δ, Y is the target variable, $i = 1, \dots \dots .. n$ represent the countries considered over $t = 1, \dots \dots \dots T$, ε_{it} is the stochastic error term. CIPS statistics is derived from equation 5 and its estimated equation is shown thus:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \qquad (6)$$

This method, which presupposes that there is a CSD, is credited by academics as being able to account for heterogeneity.

3.3.2. Estimation technique

The study employed the instrumental variable generalized method of moment (IV-GMM) because of its superiority to ordinary least squares, which is faced with challenges such as distortion in the presence of autocorrelation, endogeneity and omitted variable(s) bias (Dzator et al., 2021). Accordingly, the IV-GMM approach can handle variable omission bias and produces estimates that are consistent and effective in the presence of unknown heteroscedasticity vis-à-vis its orthogonality requirement (Baum et al., 2002). This method estimates both its reliability and its validity in a single step (see Cameron & Trivedi, 2005 for more information). Diagnostic procedures like Kleibergen-Paap F-statistics and Hansen J are taken into account to verify the genuineness of the instruments and the dependability of the models. However, it has been emphasized that the dynamic IV-GMM does not account for CSD in panel models. In light of this, the approach taken by Pesaran (2004) is followed here in an attempt to test for CSD. The Driscoll-Kraay (DK) regression is used as a robustness check for IV-GMM estimates if it is determined that there is a cross-sectional dependence. In addition to heteroskedasticity and serial correlation, this regression also yields exceptionally resilient standard errors to all types of general cross-sectional and temporal dependency. In Figure 1, we present a graphical roadmap for the entire analysis.

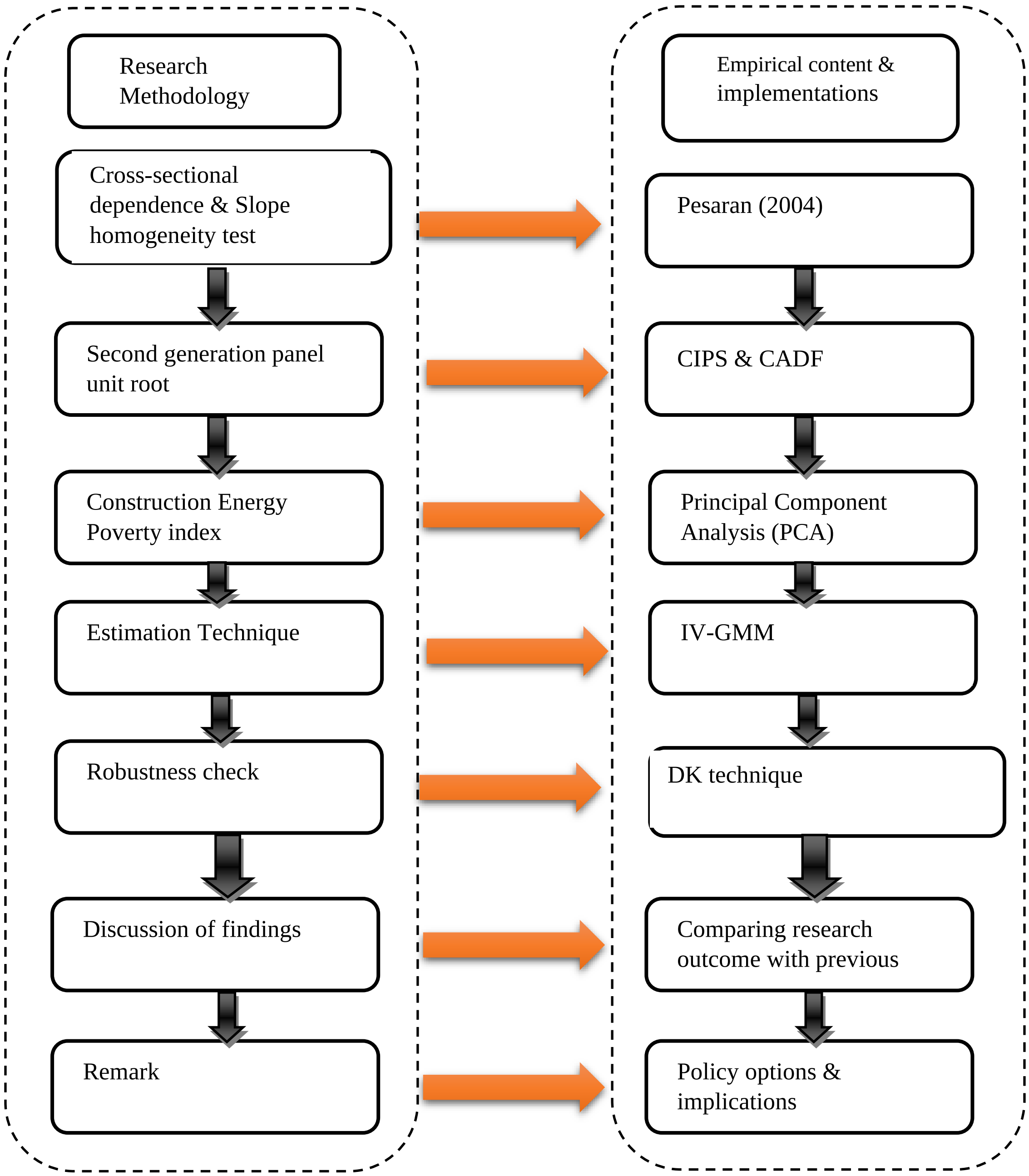

Figure 1: Hypothesized empirical approach

Source: Authors Sketch

4. Preliminary Results

4.1. Descriptive statistics and correlation analysis

Table 1 displays the findings of the variables' descriptive and correlation analyses. The outcome revealed that the mean values of ecological footprint (EF), economic growth (GDP), urbanization (URB), energy poverty variables (EP1-EP6), government effectiveness (GVT) and regulatory quality (RQ) in their raw state are 1.463, 2194.77, 41.316, 42.627, 70.728, 23.667, 23.198, 64.581, 48.776, -0.630 and -0.574 respectively. Also, the result indicates that their corresponding standard deviations are EF (0.682), GDP (2449.100), URB (16.969), EP1 (23.996), EP2 (18.894), EP3 (24.336), EP4 (27.052), EP5 (23.936), EP6 (35.615), GVT (0.565) and RQ (0.598). This further shows that GDP has the highest average value followed by access to electricity, urban, and then renewable energy consumption in SSA. The correlation analysis displayed in Table 1 lower panel demonstrates that all the explanatory variables are positively correlated with the dependent variable except EP5 and EP6, which are negatively correlated with the ecological footprint.

Table 1: Descriptive Statistics and Correlation

Variables	EF	GDP	URB	EP1	EP2	EP3	EP4	EP5	EP6	GVT	RQ
Mean	1.463	2194.777	41.316	42.627	70.728	23.667	23.198	64.581	48.776	-0.630	-0.574
Std. Dev.	0.682	2449.100	16.969	23.996	18.894	24.336	27.052	23.936	35.615	0.565	0.598
Min	0.185	233.944	15.054	3.653	11.860	-3.430	0.200	8.752	-13.436	-1.850	-2.340
Max	3.820	10892.540	90.092	100.580	100.564	99100.708	100.000	94.726	134.108	1.060	1.130
CORRELATION											
LNEF	1.000										
LNGDP	0.776	1.000									
LNURB	0.417	0.584	1.000								
EP1	0.593	0.710	0.667	1.000							
EP2	0.357	0.448	0.407	0.827	1.000						
EP3	0.590	0.582	0.346	0.873	0.640	1.000					
EP4	0.739	0.885	0.557	0.758	0.528	0.662	1.000				
EP5	-0.735	-0.578	-0.474	-0.611	-0.364	-0.653	-0.696	1.000			
EP6	-0.368	-0.239	-0.332	-0.347	-0.248	-0.316	-0.271	0.422	1.000		
GVT	0.654	0.565	0.089	0.462	0.309	0.600	0.554	-0.633	-0.192	1.000	
RQ	0.630	0.512	0.077	0.361	0.192	0.475	0.449	-0.542	-0.167	0.883	1.000

Source: Authors Compilation

4.2. Preliminary Results

Dong et al. (2018) stated that it is essential to test for cross-sectional independence in dynamic panels, especially N>T dimension to prevent ineffective and misleading results. Due to Table 2's evidence of CSD, we reject the null hypothesis that there is no cross-sectional dependency and estimate IV-GMM, a model that can handle scenarios of data series heterogeneity.

Table 2: CSD Test

Variables	CD-test	p-value
LNGDP	3.245	0.001
GDPSQ	49.479	0.000
LNURB	73.922	0.000
EP1	77.34	0.000
EP2	50.987	0.000
EP3	47.948	0.000
EP4	36.019	0.000
EP5	34.979	0.000
EP6	-2.102	0.036
GVT	-0.621	0.535
RQ	3.892	0.000

Source: Authors Compilation

Table 3 represents the estimated second-generation panel unit root of CIPS and CADF with the options of intercept and trend and the outcome for all variables shows that none is stationary at levels but after first-order differencing, they become stationary. This also entails that our variables are integrated of order one (I [1]).

Table 3: Panel Unit Root Tests (CIPS and CADF)

Variable	Level		First Difference		Order of Integration
	Intercept	Intercept and trend	Intercept	Intercept and trend	
PESARAN CIPS TEST					
LNEF	-1.211	-1.021	-4.211	-3.682	I(1)
LNGDPC	-1.312	-1.183	-5.104	-4.213	I(1)
LNURB	-1.643	-1.009	-3.538	-5.611	I(1)
EP1	-1.675	-0.235	-5.102	-4.512	I(1)
EP2	1.102	-0.225	-4.113	-3.441	I(1)
EP3	-0.621	-1.376	-4.241	-4.043	I(1)
EP4	-2.332	-1.876	-5.014	-4.385	I(1)
EP5	-1.056	-1.108	-4.111	-5.320	I(1)
EP6	-1.667	-1.387	-5.030	-3.766	I(1)
GVT	-2.023	-2.085	-4.154	-4.128	I(1)
RQ	-1.045	-1.227	-3.933	-3.844	I(1)
Pesaran CADF test					
LNEF	-1.091	-1.008	-3.442	-3.223	I(1)
LNGDPC	-1.243	-1.276	-5.132	-4.315	I(1)
LNURB	-1.771	-1.287	-3.333	-5.434	I(1)
EP1	-1.011	-0.276	-5.051	-4.112	I(1)
EP2	1.879	-1.721	-4.111	-5.034	I(1)
EP3	-2.003	-1.266	-5.003	-4.221	I(1)
EP4	-2.127	-1.277	-3.418	-4.921	I(1)
EP5	-1.771	-1.256	-4.142	-3.775	I(1)
EP6	-1.232	-1.181	-3.095	-4.002	I(1)
GVT	-2.114	-1.051	-4.811	-4.127	I(1)
RQ	-2.211	-1.143	-3.322	-4.103	I(1)

Source: Authors' compilation

4.3. Primary Findings

To establish a connection between EP and ecological sustainability in SSA, we employed the IV-GMM approach which takes care of endogeneity issues. We also incorporate two governance quality indicators such as government effectiveness and regulatory quality as interactive terms with the core explanatory variable (EP). These results are presented in Tables 4 and 5. Also, to check the consistency of the IV-GMM technique, we employed the DK method as a robust check and the results are shown in Tables 6 and 7.

TABLE 4: Estimate from IV-GMM incorporating Government effectiveness as the interaction variables

VARIABLES	1	2	3	4	5	6	7
LNGDP	-0.226**	-0.261**	-0.524**	-0.289**	-0.091**	-1.193***	-0.967***
	(0.205)	(0.206)	(0.210)	(0.240)	(0.211)	(0.189)	(0.236)
	[-2.104]	[-2.265]	[-2.497]	[-2.206]	[-2.430]	[-6.295]	[-4.103]
GDPSQ	0.033**	0.030**	0.047***	0.034**	0.019**	0.091***	0.083***
	(0.014)	(0.013)	(0.013)	(0.015)	(0.015)	(0.012)	(0.015)
	[2.330]	[2.281]	[3.519]	[2.179]	[2.280]	[7.524]	[5.609]
LNURB	-0.03**	-0.104**	-0.107***	-0.054**	-0.044**	-0.029**	-0.018**
	-0.033	-0.041	(0.036)	(0.037)	(0.035)	(0.033)	(0.040)
	[-2.905]	[2.519]	[2.972]	[-2.468]	[-2.245]	[-2.875]	[-2.458]
EPINDEX	0.062**						
	(0.031)						
	[2.010]						
EPINDEXGVT	0.113***						
	(0.019)						
	[6.029]						
EP1		0.002**					
		(0.001)					
		[2.125]					
GVT1		0.005***					
		(0.001)					
		[11.048]					
EP2			0.002**				
			(0.001)				
			[2.463]				
GVT2			0.003***				
			(0.00)				
			[8.224]				
EP3				0.002***			
				(0.001)			
				[2.855]			
GVT3				0.004***			
				(0.001)			
				[6.564]			
EP4					0.004***		
					(0.001)		
					[3.366]		
GVT4					0.004***		
					(0.001)		
					[7.145]		
EP5						-0.007***	
						(0.001)	
						[-7.995]	
GVT5						0.001**	
						(0.001)	
						[2.485]	

EP6							-0.002***
							0.00
							[-3.771]
GVT6							0.001**
							(0.001)
							[2.922]
Constant	0.228	0.194	1.131	0.367	-0.265	4.657***	3.030***
	(0.736)	(0.804)	(0.779)	(0.914)	(0.770)	(0.736)	(0.900)
	[0.309]	[0.241]	[1.452]	[0.402]	[-0.344]	[6.323]	[3.365]
Observations	525	525	525	525	525	525	525
R-squared	0.5	0.541	0.525	0.513	0.525	0.567	0.481

() is the standard error, [] is the t-statistics. *, **,*** indicate 10% 5%, and 1% level of significance respectively. Note: GVT1-GVT6 indicates the interaction of respective EP and government effectiveness

In Table 4, the outcome highlights that on aggregate, the coefficient of EP index (EPINDEX) is positive and statistically significant at the 5% level in model (1) where the index of EP computed via PCA was used to represent EP. This indicates that the unconditional impact of the EP index on ecological quality (ecological footprint) is positive and significant, that is a unit rise in EPINDEX will bring about 0.062 significant increases in ecological footprint in SSA. This finding aligns with past studies (Zhao et al. 2021; Hassan et al. 2022; Zhang et al. 2022) that observed that inadequate electricity access causes people to rely on traditional fuels which are not environment friendly. People without access to electricity are unable to use contemporary cooking appliances, so they are compelled to use readily available and inexpensive fuels, like fossil fuels or firewood, which harms the environment. The conditional impact of EPINDEX on environmental quality (that is when energy poverty interacts with government effectiveness) is positive and significant at the 1% level of significance. This means that the energy poverty index on its own worsens environmental degradation and the interaction with government effectiveness further deteriorates the environment. These results confirm the conclusions of similar African studies like Obobisa et al (2022a), and Obobisa et al (2022b) that emphasize the fact that African countries' institutions are ineffective at reducing environmental pollution. To ascertain the individual effect of energy poverty and their interaction with government effectiveness (GVT) on environmental quality, we disaggregated the energy poverty variables into EP1-EP6 (see Table 1 for definitions). The unconditional impact of EP1 on environmental quality is positive and significant at the 5% significance level while the conditional effect is also positive and significant at the 1% level of significance. This shows that access to electricity in the overall population promotes ecological damage by increasing the ecological footprint in SSA. Also, interacting access to electricity in the total population with government effectiveness yields the same directional outcome of increasing ecological footprint (EF). Similarly, urban electrification, rural electrification, and clean cooking accessibility reveal a positive and significant impact on environmental quality at both their unconditional and conditional states. The coefficients at the conditional levels seem to be higher than at the unconditional levels. This means that the government's effectiveness helps to further dampen environmental quality. On the contrary, the consumption and production of renewable energy (EP5 and EP6) have a statistically significant negative influence on environmental quality. The outcome highlights that the quality of the SSA's environment is improving as people migrate to renewable energy sources which emit less emissions when compared to traditional energy sources that emit a lot of pollution (Onuoha et al., 2023a; Onuoha et al., 2023b). This discovery aligns with Adekoya et al (2022), Ehigiamusoe and Dogan (2022) and Jian et al (2022). When EP5 and EP6 interact with government effectiveness, they increase environmental deterioration by increasing the ecological footprint in SSA. This means that EP5 and EP6 at their levels, reduce ecological footprint but with government effectiveness, the negative impact was weakened and as such endangers the health of the environment. In other words, government effectiveness reduces the negative influence of EP5 and EP6 on ecological quality via ecological footprint.

Economic growth (GDP) and the squared term of GDP indicate negative and positive significant influences on ecological footprint across specifications (1-7). Contrary to what was predicted by the EKC hypothesis, the findings support the idea that increasing income cannot be a way to protect the environment. The outcome of the study aligns with Destek and Sarkodie (2019); Dogan et al (2020) and Beyene (2022) but contradicts Ahmed and Wang (2019), Le and Ozturk (2020), Alhassan and Kwakwa (2022) and Ehigiamusoe and Dogan (2022). Unexpectedly, the coefficient of urbanization is negatively significant, suggesting that urbanization safeguards the SSA environment. This finding conflicts with prior studies that claim urbanization deteriorates the environment (Alhassan & Kwakwa, 2022; Jian et al, 2022). Our findings, however, are consistent with those of Dimnwobi et al. (2021); Charfeddine and Mrabet (2017); Ahmed and Wang (2019); Tarazkar et al. (2020). The protective effect of urbanization on ecological quality is not as expected; numerous factors can account for this outcome. First, urbanization's positive externalities and economies of scale can lead to better productivity. In an urban setting, fewer resources can be used to create the same goods. In this regard, urbanization lowers the ecological damage. Second, the growth of the service industry in SSA nations over the last two decades has been extraordinary. Urbanization is necessary for this sector because it demands a concentration of customers. Because services emit less pollution than manufacturing, this component of urbanization is also environmentally friendly. Third, it is considerably easier and less expensive to create, maintain, and run ecologically friendly public utilities like sanitation, water supply, and waste management in an urban setting. Urbanization provides more individuals with inexpensive access to environmentally friendly amenities and services. Finally, the enhanced living conditions as a result of urbanization provide people with improved housing, food, and medical care. Revenue generated by urban expansion is used to fund infrastructure initiatives, easing traffic and boosting health outcomes (Charfeddine & Mrabet, 2017; Dimnwobi et al., 2021).

TABLE 5: Estimate from IV-GMM incorporating Regulatory quality as the interaction variables

VARIABLES	1	2	3	4	5	6	7
LNGDP	-0.154	-0.335*	-0.736***	-0.333	0.022	-1.400***	-0.971***
	(0.202)	(0.195)	(0.201)	(0.221)	(0.214)	(0.185)	(0.232)
	[-0.761]	[-1.717]	[-3.663]	[-1.505]	[0.104]	[-7.581]	[-4.183]
GDPSQ	0.025*	0.034***	0.061***	0.036**	0.01	0.104***	0.084***
	(0.014)	(0.013)	(0.013)	(0.014)	(0.015)	(0.012)	(0.015)
	[1.736]	[2.720]	[4.736]	[2.490]	[0.667]	[8.751]	[5.678]
LNURB	-0.005**	-0.102**	-0.096***	-0.069*	-0.050**	-0.017**	-0.018**
	(0.036)	(0.042)	(0.037)	(0.036)	(0.035)	(0.033)	(0.037)
	[-2.131]	[-2.442]	[-2.613]	[-1.912]	[-2.418]	[-2.522]	[-2.498]
EPINDEX	0.103***						
	(0.033)						
	[3.113]						
EPINDEXRQ	0.094***						
	(0.018)						
	[5.158]						
EP1		0.003***					
		(0.001)					
		[2.807]					
RQ1		0.005***					
		(0.001)					
		[11.837]					
EP2			0.003***				
			(0.001)				
			[3.477]				
RQ2			0.003***				
			0.00				
			[9.505]				
EP3				0.003***			
				(0.001)			

				[3.492]			
RQ3				0.005***			
				(0.001)			
				[7.083]			
EP4					0.004***		
					(0.001)		
					[4.262]		
RQ4					0.005***		
					(0.001)		
					[8.074]		
EP5						0.006***	
						(0.001)	
						[8.587]	
RQ5						0.002***	
						0.00	
						[4.822]	
EP6							0.002***
							0.00
							[3.782]
RQ6							0.001**
							(0.001)
							[2.322]
Constant	0.034	0.501	1.902**	0.514	-0.647	5.318***	3.042***
	(0.731)	(0.766)	(0.751)	(0.846)	(0.785)	(0.713)	(0.891)
	[0.047]	[0.654]	[2.531]	[0.607]	[-0.825]	[7.454]	[3.413]
Observations	525	525	525	525	525	525	525
R-squared	0.487	0.558	0.544	0.524	0.528	0.592	0.482

() is the standard error, [] is the t-statistics. *, **,*** indicate 10% 5% and 1% level of significance respectively. Note: RQ1-RQ6 indicates the interaction of respective EP and Regulatory quality

Table 5 presents the role of regulatory quality in the EP-environmental quality nexus. The result demonstrates that the ecological footprint in SSA is positively and significantly impacted by the EP index as well as its interaction with regulatory quality. This suggests that the index of EP damages the ecological quality by increasing the ecological footprint. This outcome aligns with Zhao et al. (2021) and Zhang et al. (2022) and is unsurprising given the prevalence of EP in SSA and its negative effect on the environment (Dimnwobi et al., 2021). As noted by Dimnwobi et al (2022c), EP is explained as inadequate access to clean fuels and a heavy dependence on conventional polluting fuels like biomass and firewood. This biomass is primarily burned in dirty and inefficient stoves across SSA and is inimical to lowering environmental pollution. Hence, the continued use of conventional fuels in SSA has several detrimental environmental repercussions (Dimnwobi et al., 2022b; Dimnwobi et al 2022c). The conditional impact that is, the interaction of EPINDEX with regulatory quality further degrades SSA's environment. This outcome is plausible given weak institutions which undermine the implementation of public policies in SSA. More specifically, SSA's subpar institutions encourage domestic and foreign investment in the production of dirty export items and present chances for the transfer of antiquated, environmentally unfriendly technologies. This finding aligns with Hassan et al (2020), Teng et al (2020) and Azam et al (2021). For the case of the individual impact of EP and their interaction with regulatory quality (RQ) on ecological footprint, we observed that both the unconditional and conditional impact of EP1 on environmental quality is positive and significant at the 1% significant levels. This shows that access to electricity in the total population increases environmental degradation in SSA. Also, the interaction of EP2-EP6 with regulatory quality reveals a positive and significant impact on environmental quality at 1% significance levels. This implies that energy poverty irrespective of the indicator endangers environmental quality and interacting with regulatory quality helps to further dampen environmental quality in SSA.

Economic growth (GDP) exerts a negative and significant impact on EF in Models 2, 3, 6 and 7 but was not significant in affecting EF in specs 1, 4 and 5. The squared term of GDP exhibits a positive and significant influence on EF across the models except for Model 5. The results reinforce the premise that raising income cannot be a strategy to safeguard the environment, contrary to what the EKC hypothesis suggested. The study's findings are consistent with those of Destek and Sarkodie (2019), Dogan et al (2020), and Beyene (2022). Urbanization reveals a negative and significant impact on EF. This means that a unit increase in urban population will lead to a reduction in the ecological footprint in SSA and this aligns with the outcomes of Munir and Ameer (2018); Dimnwobi et al. (2021) and Beyene (2022). The increase in the service sector, a fall in fertility, higher educational standards, and, most crucially, the development of green technologies are all benefits of urbanization that contribute to the improvement of the environment. Although the bulk of research (Dogan & Turkekul, 2016; Alhassan & Kwakwa, 2022; Munir & Ameer, 2022; Jian et al, 2022) suggests that urbanization has a detrimental impact on environmental quality by placing a greater load on rare natural resources, our findings reveal that there may also be a way to enhancing ecological quality while urbanization occurs. It is well acknowledged in the literature that urban populations tend to have higher standards of living than rural ones, and they frequently put a great deal of strain on the environment (Alhassan & Kwakwa, 2022). Howbeit, this pressure can be used to foster greater cooperation and more conversation about methods and technology solutions for mitigating municipal environmental concerns. One example is enhanced public infrastructure. According to Munir and Ameer (2018), this technical advancement may improve energy efficiency and hasten the transition from fossil fuels to clean energy sources. It may also encourage green foreign direct investments and R&D spending (Beyene, 2022). In this study, we used several diagnostic measures to evaluate the robustness of the IV-GMM models. In this model, the Kleibergen-Paap LM statistic, Kleibergen-Paap Wald F statistic and Cragg-Donald Wald F statistic for exogeneity of instruments, and the Wald test for the joint validity of estimated coefficients are some of the checks performed. Our findings are suitable for inference and policymaking, and all information criteria in all models firmly demonstrate the models' fitness. In the interest of brevity, however, we will not detail the outcomes of these diagnostic measures here; instead, they can be provided upon request.

4.4. Robustness check

To confirm the consistency of the econometric technique used in the analysis, we adopted the DK technique and the results are presented in Tables 6 and 7. In Table 6, government effectiveness interacted with energy poverty and a similar result to those of IV-GMM was discovered. For instance, the energy poverty index conditionally and unconditionally exerts a positive and significant influence on EF. Individually, EP1-EP6 exhibits a positive and significant impact on ecological footprint conditionally and unconditionally. However, while EP5 and EP6 unconditionally reduce EF in the IV-GMM approach, they exert a positive and significant impact on EF in the DK method. GDP and GDPSQ yield negative and positive impacts on EF respectively except for spec. [5] where GDP and GDPSQ have a positive influence on EF. Urbanization also exerts a negative and significant impact on EF across all specifications.

Table 6: DK results incorporating Government effectiveness as the interaction variables

VARIABLES	1	2	3	4	5	6	7
LNGDP	-0.718*	-0.336**	-0.302**	-0.410**	0.274**	-0.545**	-0.369**
	(0.382)	(0.041)	(0.033)	(0.031)	(0.001)	(0.368)	(0.434)
	[-1.882]	[-2.622]	[-2.697]	[-2.772]	[-2.548]	[-2.481]	[-2.850]
GDPSQ	0.078**	0.049**	0.046**	0.056**	0.044**	0.053**	0.054**
	(0.032)	(0.044)	(0.037)	(0.042)	(0.040)	(0.032)	(0.036)
	[2.466]	[2.127]	[2.248]	[2.329]	[2.098]	[2.638]	[2.502]
LNURB	-0.640***	-0.313**	-0.478***	-0.541**	-0.663***	-0.705***	-0.688***
	(0.177)	(0.128)	(0.159)	(0.185)	(0.159)	(0.217)	(0.220)
	[-3.608]	[-2.449]	[-3.004]	[-2.920]	[-4.158]	[-3.254]	[-3.125]
EPINDEX	0.039***						
	(0.007)						

	[5.321]						
EPINDEXGVT	0.021**						
	(0.009)						
	[2.365]						
GVT1		0.002***					
		(0.001)					
		[3.124]					
EP1		0.002*					
		(0.001)					
		[2.105]					
GVT2			0.001***				
			0.00				
			[3.024]				
EP2			0.001				
			(0.001)				
			[2.786]				
GVT3				0.001			
				(0.001)			
				[0.982]			
EP3				0.001***			
				0.00			
				[3.327]			
GVT4					0.002*		
					(0.001)		
					[1.831]		
EP4					0.002		
					(0.002)		
					[1.132]		
GVT5						0.002***	
						0.00	
						[4.399]	
EP5						0.006***	
						(0.002)	
						[3.190]	
GVT6							0.001**
							(0.001)
							[2.609]
EP6							0.000*
							0.00
							[1.838]
Constant	3.682**	1.396	1.899	2.262	2.308	4.449***	2.598
	(1.562)	(1.759)	(1.499)	(2.001)	(1.863)	(1.456)	(1.670)
	[2.358]	[0.794]	[1.267]	[1.130]	[1.239]	[3.056]	[1.555]
Observations	560	560	560	560	560	560	560
Number of groups	35	35	35	35	35	35	35

() is the standard error, [] is the t-statistics. *, **,*** indicate 10% 5% and 1% level of significance respectively. Note: GVT1-GVT6 indicates the interaction of respective EP and government effectiveness

Finally, when regulatory quality was employed to interact with energy poverty as indicated in Table 7, we observed that GDP and GDPSQ exhibit negative and positive impacts on EF respectively. This result is similar to the result of the IV-GMM method. Also, URB yields a similar result as it exerts a negative and significant impact on EF across specifications. The energy poverty index at unconditional and conditional levels exerts a negative and significant impact on EF. Finally, EP5 and 6 exhibits positive and significant impact on EF in SSA which tallies with the IV-GMM outcome. The majority of the conclusions from the IV-GMM result are supported by this outcome.

Table 7: DK results incorporating Regulatory quality as the interaction variables

VARIABLES	1	2	3	4	5	6	7
LNGDP	-0.919*	-0.593**	-0.43**	-0.514**	-0.719**	-0.379**	-0.218**
	(0.472)	(0.065)	(0.444)	(0.074)	(0.089)	(0.408)	(0.387)
	[-1.948]	[-2.049]	[-2.969]	[-2.895]	[-2.220]	[-2.929]	[-2.563]
GDPSQ	0.094**	0.074**	0.063**	0.066**	0.084**	0.047**	0.049**
	(0.038)	(0.046)	(0.037)	(0.046)	(0.048)	(0.034)	(0.032)
	[2.444]	[1.610]	[1.715]	[1.418]	[1.735]	[2.364]	[2.549]
LNURB	- 0.649***	- 0.461***	- 0.681***	- 0.581***	- 0.788***	- 0.830***	- 0.813***
	(0.171)	(0.143)	(0.168)	(0.194)	(0.182)	(0.219)	(0.239)
	[-3.794]	[-3.212]	[-4.064]	[-2.997]	[-4.331]	[-3.783]	[-3.400]
EPINDEX	- 0.056***						
	(0.019)						
	[-3.020]						
EPINDEXRQ	-0.058*						
	(0.028)						
	[-2.105]						
RQ1		-0.001					
		(0.001)					
		[-1.145]					
EP1		- 0.004***					
		(0.001)					
		[-2.960]					
RQ2			- 0.001***				
			0.00				
			[-3.365]				
EP2			-0.002				
			(0.001)				
			[-1.454]				
RQ3				-0.010			

				(0.001)			
				[-0.214]			
EP3				-0.002***			
				(0.001)			
				[-3.206]			
RQ4					-0.004*		
					(0.002)		
					[-1.926]		
EP4					-0.002		
					(0.003)		
					[-0.729]		
RQ5						0.124	
						0.00	
						[0.043]	
EP5						0.007***	
						(0.002)	
						[3.688]	
RQ6							0.003**
							(0.001)
							[-2.316]
EP6							0.002***
							0.00
							[-5.695]
Constant	4.322**	2.462	2.596	2.671	3.931*	4.005**	2.189
	(1.861)	(1.860)	(1.519)	(2.144)	(2.185)	(1.519)	(1.483)
	[2.323]	[1.324]	[1.709]	[1.246]	[1.799]	[2.636]	[1.476]
Observations	560	560	560	560	560	560	560
Number of groups	35	35	35	35	35	35	35

() is the standard error, [] is the t-statistics. *, **,*** indicate 10% 5% and 1% level of significance respectively. Note: RQ1-RQ6 indicates the interaction of respective EP and Regulatory quality

4.5. Further discussion of the empirical findings

The lack of access to affordable energy sources in SSA has serious consequences for the region's ecosystem. Deforestation, soil erosion, biodiversity loss, and increased carbon emissions are exacerbated by a lack of access to modern energy sources. Environmental degradation is exacerbated by the interplay between government ineffectiveness and the quality of legislation. Environmental impacts are compounded by poor governance and regulation, hampering attempts to tackle energy poverty and promote sustainable energy solutions. The economic cost of these problems is high as they slow progress, reduce production and make the region more vulnerable to climate change and natural disasters. By understanding the economic impact of energy poverty and its detrimental impact on the environment, decision-makers can prioritize initiatives to address energy access challenges, improve governance, strengthen regulations and promote sustainable energy solutions. This information can guide the development of effective policies, investments and interventions aimed at reducing energy poverty, minimizing ecological damage and promoting sustainable development in SSA.

This study further refutes the environmental Kuznets curve hypothesis, which held that higher GDP would lead to better environmental protection. Instead, this research shows a differentiated relationship between positive and negative impacts on environmental impacts. That is, GDP growth has been shown to have unintended consequences, including higher resource consumption and environmental degradation. Above a certain income level, however, environmental degradation accelerates significantly, as shown by the positive impact of the squared GDP term. These results underscore the importance of adopting specific policies and practices that reduce the link between economic growth and environmental degradation, promote sustainability, and account for the complex nonlinearity of the relationship between income and environmental protection.

5. Conclusion and Policy Implications

Employing government effectiveness and regulatory quality as moderating variables to represent the efficacy of the governance environment, this research investigated the influence of EP for 35 SSA nations from 2005 to 2020. Specifically, this study aimed to explore the relationship between energy poverty, governance quality, and the environmental impact in Sub-Saharan Africa (SSA). By employing the IV-GMM technique which addresses the likelihood of endogeneity issues and incorporating various variables, including energy poverty indicators, governance quality measures, and control variables, the study provided empirical insights into the dynamics of environmental sustainability in the region. The findings of the study reveal several important empirical observations. Firstly, the analysis confirmed the positive association between energy poverty and ecological footprint, indicating that inadequate access to clean energy sources contributes to environmental degradation. This aligns with previous studies that highlight the detrimental effects of energy poverty on the environment.

Furthermore, the study examined the role of governance quality in moderating the relationship between energy poverty and environmental impact. The results indicated that governance quality, represented by government effectiveness and regulatory quality, worsens the environmental degradation caused by energy poverty. Weak institutions and ineffective governance hinder the implementation of environmental policies, allowing for the persistence of environmentally damaging practices. The study also investigated the impact of economic growth and urbanization on ecological footprint. Contrary to the environmental Kuznets curve hypothesis, which suggests a negative relationship between economic growth and environmental degradation, the findings revealed that economic growth has adverse effects on the environment. The squared term of GDP demonstrated a positive impact, indicating that beyond a certain income level, environmental degradation accelerates significantly.

Additionally, the study highlighted the surprising protective effect of urbanization on ecological quality in SSA. Urbanization was found to have a negative impact on ecological footprint, contradicting the common perception that urbanization exacerbates environmental problems. By implication, the positive externalities, economies of scale, improved living conditions, and better infrastructure associated with urbanization in SSA contribute to a more sustainable environment. The robustness of the findings was confirmed through diagnostic measures, including Kleibergen-Paap LM statistic, Cragg-Donald Wald F statistic, and information criteria, which supported the validity and reliability of the econometric models.

The implications of these findings have generated some interesting policy insights that are significant for policymakers and stakeholders in Sub-Saharan Africa. Therefore, it is clear from the results that policymakers in SSA have to enhance their capacity in addressing energy poverty and enhancing environmental sustainability through the following suggestions. Access to clean and affordable electricity is crucial for economic development and environmental sustainability. Expanding policies such as rural electrification programs, microgrid development, and investment in off-grid solutions are therefore needed to promote access to electricity and reduce the incidence of EP. This will help decrease the negative impact of EP on the environment. Conceivably, government assistance is essential for addressing energy poverty in SSA by expanding spending and incentives to expediently create the needed energy infrastructure and facilitate access to clean, cheap, and effective energy (particularly to improve electricity access for rural areas). The prevalence of the usage of wood and other polluting traditional energy sources in SSA more than in other continents according to IEA (2020) provides evidence of this. Likewise, to secure a smooth energy transition without endangering the current energy supply, the usage of the abundant renewable energy endowments in SSA should be accorded significant action. With the abundance of renewable energy resources in the region, investment in renewable energy should be propelled through policies such as tax incentives, feed-in tariffs, and renewable portfolio standards. This will support sustainable energy practices and lessen reliance on fossil fuels.

Considerable attention towards implementing policies to promote energy-efficient practices in households, industries, and transportation such as building codes, labelling requirements, and energy audits should be prioritised. In this regard, strengthening regional energy-efficiency initiatives like the African Energy Efficiency Programme of the African Energy Commission (AFREC) becomes necessary to reduce energy consumption and promote sustainable practice. Subsequently, the convergence of energy labelling rules for appliances and illumination, as well as the creation and application of Minimum Energy Performance Standards (MEPS) at the national level and throughout the continent, becomes appropriate.

Our results pointedly support the IEA (2020) study findings about the SSA region's unacceptable EP position and the consequences of its vulnerability to climate improvement challenges. As a result, provincial authorities have to uphold domestic laws that encourage the use of renewable energy and international climate commitments by boosting incentive programs for consumer use and/or aiding investments in environmentally friendly innovations. SSA regional authorities could also contemplate the adoption of market-inclined procedures like the "polluter-pays" practice and carbon pollution charges as a preventive tactic to discourage polluters from causing environmental damage. In particular, the study findings point to the feeble nature of regulatory quality in SSA, emphasising the need to intensify regulatory frameworks that promote sustainable energy practices. This can include regulations that require utilities to source a certain percentage of their energy from renewable sources, regulations that promote energy-efficient practices, and regulations that penalize unsustainable conduct. Furthermore, to aid in the shift to a low-carbon energy system, SSA governments should tighten their regulatory structures. This can be accomplished by fostering laws and policies that encourage the use of energy-efficient technologies and renewable energy sources, as well as by gradually eliminating subsidies for fossil fuels.

Similarly, government effectiveness was found to be ineffectual in the EP-environmental sustainability nexus in SSA. Hence, improving governance and public participation is essential for addressing the detrimental influence of EP on ecological preservation in SSA. This can be achieved through greater transparency, accountability, and inclusive participation in decision-making processes, as well as the promotion of civic education and awareness-raising campaigns on the links between energy, poverty, and the environment. Also, good governance practices should be enshrined in public administration in the region to reduce corruption and promote sustainable energy sector management practices. Regular capacity building through training and education programs for policymakers, regulators, and industry stakeholders is equally paramount to promoting sustainable energy practices and improving regulatory quality. To ensure that national energy regulations and capacity-building strategies follow the environmental intentions and international benchmarks of the Paris climate pact and the 2030 Agenda for sustainable development, SSA authorities are strongly encouraged to intensify eco-friendly programmes via improved collaborations among nations, regulatory authorities, economic stakeholders, and global sustainability associates.

To entrench green production and consumption patterns, regional authorities should devote more effort to understanding how economic practices influence the quality of the environment. The findings from our research demonstrate that economic growth in the SSA region markedly influences environmental pollution. Therefore, the main challenge for SSA nations is to come up with innovative strategies for encouraging regional economic prosperity without causing environmental damage. The sustainable diversification of each nation’s production structure would be a good place to start to improve output for both local and international consumption while reducing dependency on polluting natural resources and mineral deposits. As this is happening, the approach should be focused on fostering more environment-conscious, sustainable, equitable, and inclusive economic growth within the region. Besides, bearing in mind the possibility of unequal economic advancement in the continent, countries in SSA with less severe energy poverty could also contribute to the reduction of energy poverty and the furtherance of economic improvement. These countries should promote policies that boost the production and use of renewable energy while keeping an open line of communication to gauge the effectiveness of such policies. Moreover, since macroeconomic policy includes economic growth enhancement measures, SSA policymakers should prioritize the maintenance of a supportive (hard and soft) macroeconomic environment to stimulate energy sector growth, via a special focus on renewable energy industries, transfer of knowledge, and innovation-driven investments in a bid to encourage the reformation and advancement of the energy sector in the continent.

While this study does its best to provide a policy perspective beneficial to the energy poverty-environmental sustainability debate, nevertheless it is by no means definitive. There are thus underlying constraints that provide motivations for further investigation. These limitations include the focus on Sub-Saharan Africa (SSA) which may not be directly applicable to other regions or countries. The specific socio-economic, political, and environmental characteristics of SSA may influence the results and limit their generalizability. Thus, comparing findings among SSA countries and sub-regions within the continent will be useful for drawing parallels regarding nation-states, natural resources, and governance systems. Intercontinental assessments with developed regions, which differ in a variety of ways, could be yet another subject of investigation. Similarly, the use of governance quality variables as proxies may not capture all dimensions of governance and may not fully represent the complex governance-environment relationship. Furthermore, despite efforts to include control variables, there is a possibility of omitted variables that could influence the relationship between energy poverty, governance quality, and environmental sustainability. Factors such as technological advancements, policy interventions, and cultural factors are not explicitly accounted for and may impact the results. In general, research in this area needs to continue as new information, theories, and methods become available. Lastly, the 2015-launched United Nations Sustainable Development Goals require increased environmental sustainability as a major priority. Hence, SSA countries are obligated to take active measures to alleviate energy poverty, issues with economic growth and governance challenges, and environmental responsibility for the interest of their citizens and society in addition to the rest of the world with fewer than seven years till the 2030 target.

References

Adekoya, O.B., Ajayi, G.E., Suhrab, M., & Oliyide, J.A. (2022). How critical are resource rents, agriculture, growth, and renewable energy to environmental degradation in the resource-rich African countries? The role of institutional quality. *Energy Policy*, 164. https://doi.org/10.1016/j.enpol.2022.112888

Afolabi, J. A. (2023). Natural resource rent and environmental quality nexus in Sub-Saharan Africa: Assessing the role of regulatory quality. *Resources Policy*, 82, 103488. https://doi.org/10.1016/j.resourpol.2023.103488

Ahmed, Z., & Wang, Z. (2019). Investigating the impact of human capital on the ecological footprint in India: An empirical analysis. *Environmental Science and Pollution Research*, 26, 26782–26796. https://doi.org/10.1007/s11356-019-05911-7

Alhassan, H., & Kwakwa, P.A. (2022). The effect of natural resources extraction and public debt on environmental sustainability. *Management of Environmental Quality*. https://doi.org/10.1108/MEQ-07-2022-0192

Amin, N., Shabbir, M. S., Song, H., Farrukh, M. U., Iqbal, S., & Abbass, K. (2023). A step towards environmental mitigation: Do green technological innovation and institutional quality make a difference? *Technological Forecasting and Social Change*, 190. https://doi.org/10.1016/j.techfore.2023.122413

Ansari, M.A., Villanthenkodath, M.A., Akram, V., & Rath, B.N. (2022). The nexus between ecological footprint, economic growth, and energy poverty in sub-Saharan Africa: A technological threshold approach. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02377-5

Apergis, N., Polemis, M. & Soursou, S.E. (2021). Energy poverty and education: fresh evidence from a panel of developing countries. *Energy Economics*, 106. https://doi.org/10.1016/j.eneco.2021.105430

Azadi, H., Verheijke, G., & Witlox, F. (2011). Pollute first, clean up later? *Global and Planetary Change*, 78(3-4), 77-82. https://doi.org/10.1016/j.gloplacha.2011.05.006

Azam, M., Liu, L. & Ahmad, N. (2021). Impact of institutional quality on environment and energy consumption: Evidence from developing world. *Environment, Development and Sustainability*, 23, 1646-1667. https://doi.org/10.1007/s10668-020-00644-x

Baum, C.F, Schaffer, M.E., & Stillman, S. (2002). Instrumental variables and GMM: Estimation and testing. Boston College Working Papers in Economics No. 545.

Bello, M. O., Erdogan, S., & Ch'Ng, K. S. (2022). On the convergence of ecological footprint in African countries: New evidences from panel stationarity tests with factors and gradual shifts. *Journal of Environmental Management*, 322, 116061. https://doi.org/10.1016/j.jenvman.2022.116061

Beyene, S.D. (2022). Human activities and environmental quality: Evidence beyond the conventionalEKC hypothesis. *Heliyon*, 8. https://doi.org/10.1016/j.heliyon.2022.e10756

Bildirici, M. (2022). The impacts of governance on environmental pollution in some countries of Middle East and sub-Saharan Africa: The evidence from panel quantile regression and causality. *Environmental Science and Pollution Research*, 29, 17382-17393. https://doi.org/10.1007/s11356-021-15716-2

Bilgili, F., Ozturk, I., Kocak, E., Kuskaya, S., & Cingoz, A. (2022). The nexus between access to electricity and CO2 damage in Asian countries: The evidence from quantile regression models. *Energy & Buildings*, 256, 1-14. https://doi.org/10.1016/j.enbuild.2021.111761

Butt, S., FaisaL, F., Chohan, M.A., Ali, A., & Ramakrishnan, S. (2023). Do shadow economy and institutions lessen the environmental pollution? Evidence from Panel of ASEAN-9 Economies. *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-023-01217-9

Calvin, K., Pachauri, S., De Cian, E., & Mouratiadou, I. (2016). The effect of African growth on future global energy, emissions, and regional development. *Climatic Change*, 136, 109-125. http s://doi.org/10.1007/s10584-013-0964-4

Cameron, A.C., & Trivedi, P.K. (2005). Micro econometrics: Methods and applications. UK: Ca mbridge university press

Charfeddine, L., & Mrabet, Z. (2017). The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. *Renewable and Sustainable Energy Reviews*, 76, 138-154. https://doi.org/10.1016/j.rser.2017.03.031

Das, A., & Sethi, N. (2023). Modelling the environmental pollution-institutional quality nexus in low- and middle-income countries: Exploring the role of financial development and educational level. *Environment, Development and Sustainability*, 25, 1492-1518. https://doi.org/10.1007/s10668-021-02105-5

Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *Science of The Total Environment*, 650, 2483-2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

Dimnwobi, S. K., Ekesiobi, C., Madichie, C. V., & Asongu, S.A. (2021). Population dynamics and environmental quality in Africa. *Science of The Total Environment*, 797, 1-11. https://doi.org/10.1016/j.scitotenv.2021.149172

Dimnwobi, S.K., Madichie, C.V., Ekesiobi, C., & Asongu, S.A. (2022a). Financial development and renewable energy consumption in Nigeria. *Renewable Energy*, 192, 668-677. https://doi.org/10.1016/j.renene.2022.04.150

Dimnwobi, S.K., Onuoha, F.C., Uzoechina, B.I., Ekesiobi, C. & Nwokoye, E.S. (2022b). Does public capital expenditure reduce energy poverty? Evidence from Nigeria. *International Journal of Energy Sector Management*. https://doi.org/10.1108/IJESM-03-2022-0008

Dimnwobi, S.K., Okere, K.I., Onuoha, F.C., & Ekesiobi, C. (2022c). Energy poverty, environmental degradation and agricultural productivity in Sub-Saharan Africa. *International Journal of Sustainable Development & World Ecology*, 30(4), 428-444. https://doi.org/10.1080/13504509.2022.2158957

Dimnwobi, S.K., Nwokoye, E.S., Igbanugo, C.I., Ekesiobi, C.S., & Asongu, S.A. (2023). Assessment of energy efficiency investment in Onitsha business cluster, Nigeria. *International Journal of Energy Sector Management*. https://doi.org/10.1108/IJESM-11-2021-0012

Dogan, E., & Turkekul, B. (2016). CO2 emissions, real output, energy consumption, trade, urbanization and financial development: Testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research*, 23(2), 1203–1213. https://doi.org/10.1007/s11356-015-5323-8

Dogan, E., Ulucak, R., Kocak, E., & Isik, C. (2020). The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. *Science of the Total Environment*, 723, 138063. https://doi.org/10.1016/j.scitotenv.2020.138063

Dong, K., Sun, R., & Dong, X. (2018). CO2 emissions, natural gas and renewables, economic growth: Assessing the evidence from China. *Science of the Total Environment*, 640-641, 293-302. https://doi.org/10.1016/j.scitotenv.2018.05.322

Dzator, M., Acheampong, A. O., & Dzator, J. (2021). Does transport infrastructure development contribute to carbon emissions? Evidence from developing countries. *Environmental Sustainability and Economy*, 19-33. https://doi.org/10.1016/B978-0-12-822188-4.00012-9

Edziah, B.K., Sun, H., Adom, P. K., Wang, F., & Agyemang, A. O. (2022). The role of exogenous technological factors and renewable energy in carbon dioxide emission reduction in Sub-Saharan Africa. *Renewable Energy*, 196, 1418-1428. https://doi.org/10.1016/j.renene.2022.06.130

Ehigiamusoe, K.U., & Dogan, E. (2022). The role of interaction effect between renewable energy consumption and real income in carbon emissions: Evidence from low-income countries. *Renewable and Sustainable Energy Reviews*, 154, 111883. https://doi.org/10.1016/j.rser.2021.111883

Ehigiamusoe, K.U., Majeed, M.T., & Dogan, E. (2022). The nexus between poverty, inequality and environmental pollution: Evidence across different income groups of countries. *Journal of Cleaner Production*, 341, 1-12. https://doi.org/10.1016/j.jclepro.2022.130863

Evans, O., & Mesagan, E. P. (2022). ICT-trade and pollution in Africa: Do governance and regulation matter? *Journal of Policy Modeling*, 44(3), 511-531. https://doi.org/10.1016/j.jpolmod.2022.06.003

Gök, A., & Sodhi, N. (2021). The environmental impact of governance: A system-generalized method of moments analysis. Environmental Science and Pollution Research, 28, 32995–33008. https://doi.org/10.1007/s11356-021-12903-z

González-Eguino, M. (2015). Energy poverty: An overview. *Renewable and Sustainable Energy Reviews*, 47, 377-385. https://doi.org/10.1016/j.rser.2015.03.013

Grossman, G., & Krueger, A. (1991) Environmental impacts of a North American free trade agreement. National Bureau of Economics Research Working Paper, No. 3194. https://doi.org/10.3386/w3914

Hassan, S. T., Khan, S. U. D., Xia, E., & Fatima, H. (2020). Role of institutions in correcting environmental pollution: An empirical investigation. *Sustainable Cities and Society*, 53, 101901. https://doi.org/10.1016/j.scs.2019.101901

Hassan, S.T., Batool, B., Zhu, B. & Khan, I. (2022). Environmental complexity of globalization, education, and income inequalities: new insights of energy poverty. *Journal of Cleaner Production*, 340. https://doi.org/10.1016/j.jclepro.2022.130735

Hussain, M., & Dogan, E. (2021). The role of institutional quality and environment-related technologies in environmental degradation for BRICS. *Journal of Cleaner Production*, 304, 127059. https://doi.org/10.1016/j.jclepro.2021.127059

Ibrahim, R. L., Ozturk, I., Al-Faryan, M. A. S., & Al-Mulali, U. (2022). Exploring the nexuses of disintegrated energy consumption, structural change, and financial development on environmental sustainability in BRICS: Modulating roles of green innovations and regulatory quality. *Sustainable Energy Technologies and Assessments*, 53, 102529. https://doi.org/10.1016/j.seta.2022.102529

International Energy Agency (2019). World energy outlook. IEA, Paris

International Energy Agency (2020). World energy outlook, IEA, Paris

Jahanger, A., Awan, A., Anwar, A., & Adebayo, T. S. (2023a) Greening the Brazil, Russia, India, China and South Africa (BRICS) economies: Assessing the impact of electricity consumption, natural resources, and renewable energy on environmental footprint. *Natural Resources Forum*. https://doi.org/10.1111/1477-8947.12294

Jahanger, A., Hossain, M. R., Onwe, J. C., Ogwu, S. O., Awan, A., & Balsalobre-Lorente, D. (2023b). Analyzing the N-shaped EKC among top nuclear energy generating nations: A novel dynamic common correlated effects approach. *Gondwana Research*, 116, 73-88. https://doi.org/10.1016/j.gr.2022.12.012

Jahanger, A., Hossain, M. R., Onwe, J. C., Ogwu, S. O., Awan, A., & Balsalobre-Lorente, D. (2023c). Analyzing the N-shaped EKC among top nuclear energy generating nations: A novel dynamic common correlated effects approach. *Gondwana Research*, 116, 73-88. https://doi.org/10.1016/j.gr.2022.12.012

Jahanger, A., Ozturk, I., Onwe, J.C., Joseph, T. E., & Hossain, M.R. (2023d). Do technology and renewable energy contribute to energy efficiency and carbon neutrality? Evidence from top ten manufacturing countries. *Sustainable Energy Technologies and Assessments*, 56, 103084. https://doi.org/10.1016/j.seta.2023.103084

Jian, L., Chuimin, K., Jijian, Z., Yusheng, K., & Ntarmah, A.H. (2022). The relationship between economic growth and environmental degradation: could West African countries benefit from EKC hypothesis? *Environmental Science and Pollution Research*, 29, 73052-73070. https://doi.org/10.1007/s11356-022-21043-x

Kibria, M. G. (2023). Ecological footprint in Bangladesh: Identifying the intensity of economic complexity and natural resources. *Heliyon*, 9(4), e14747. https://doi.org/10.1016/j.heliyon.2023.e14747

Kirikkaleli, D., Sofuoğlu, E., & Ojekemi, O. (2023). Does patents on environmental technologies matter for the ecological footprint in the USA? Evidence from the novel Fourier ARDL approach. *Geoscience Frontiers*, 14(4), 101564. https://doi.org/10.1016/j.gsf.2023.101564

Le, H.P., & Ozturk, I. (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. *Environmental Science and Pollution Research*, 27, 22680-22697. https://doi.org/10.1007/s11356-020-08812-2

Leimbach, M., Roming, N., Schultes, A., & Schwerhoff, G. (2018). Long-term development perspectives of sub-saharan africa under climate policies. *Ecological Economics*, 144, 148-159. https://doi.org/10.1016/j.ecolecon.2017.07.033

Mesagan, E. P., & Olunkwa, C. N. (2022). Heterogeneous analysis of energy consumption, financial development, and pollution in Africa: The relevance of regulatory quality. *Utilities Policy*, 74, 101328. https://doi.org/10.1016/j.jup.2021.101328

Mewamba-Chekem, J., & Noumessi, F.W. (2021). Do energy poverty and energy consumption drive CO2 emissions? Evidence from Sub-Saharan Africa. *South Asian Journal of Social Studies and Economics*, 11(4), 23-37. https://doi.org/10.9734/SAJSSE/2021/v11i430291

Muoneke, O. B., Okere, K. I., & Egbo, O. P. (2023). Does political conflict tilt finance-renewable energy dynamics in Africa? Accounting for the multi-dimensional approach to financial development and threshold effect of political conflict. *Heliyon*, 9 https://doi.org/10.1016/j.heliyon.2023.e14155

Munir, K., & Ameer, A. (2018). Effect of economic growth, trade openness, urbanization, and technology on Enviornment of Asian Emerging Economies. *Management of Environmental Quality: An International Journal*, 29(6), 1123-1134. https://doi.org/10.1108/MEQ-05-2018-0087

Munir, K., & Ameer, A. (2022). Assessing nonlinear impact of urbanization, economic growth, technology, and trade on environment: evidence from African and Asian emerging economies. *GeoJournal*, 87, 2195–2208 (2022). https://doi.org/10.1007/s10708-020-10366-2

Nchofoung, T.N., & Asongu, S.A. (2022). Effects of infrastructures on environmental quality contingent on trade openness and governance dynamics in Africa. *Renewable Energy*, 189, 152-163. https://doi.org/10.1016/j.renene.2022.02.114

Nguyen, C.P., & Su, T.D. (2021). The 'vicious cycle' of energy poverty and productivity: Insights from 45 developing countries. *Environmental Science and Pollution Research*, 28, 56345-56362. https://doi.org/10.1007/s11356-021-14614-x

Nguyen, C.P., Su, T.D., Bui, T.D., Dang, V.T.B. and Nguyen, B.Q. (2021). Financial development and energy poverty: Global evidence. *Environmental Science and Pollution Research*, 28(26), 35188-35225. https://doi.org/10.1007/s11356-021-13038-x

Ni, Z., Yang, J., & Razzaq, A. (2022). How do natural resources, digitalization, and institutional governance contribute to ecological sustainability through load capacity factors in highly resource-consuming economies? *Resources Policy*, 79, 103068. https://doi.org/10.1016/j.resourpol.2022.103068

Obobisa, E. S., Chen, H., & Mensah, I. A. (2022a). The impact of green technological innovation and institutional quality on CO2 emissions in African countries. *Technological Forecasting and Social Change*, 180, 121670. https://doi.org/10.1016/j.techfore.2022.121670

Obobisa, E.S., Chen, H. & Mensah, I.A. (2022b). Transitions to sustainable development: the role of green innovation and institutional quality. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-022-02328-0

Okere, K.I., Dimnwobi, S.K., Ekesiobi, C., & Onuoha, F.C. (2023). Turning the tide on energy poverty in sub-Saharan Africa: Does public debt matter? *Energy*, 128365. https://doi.org/10.1016/j.energy.2023.128365

Onuoha, F.C., Dimnwobi, S. K., Okere, K. I., & Ekesiobi, C. (2023a). Funding the green transition: Governance quality, public debt, and renewable energy consumption in Sub-Saharan Africa. *Utilities Policy*, 82, 101574. https://doi.org/10.1016/j.jup.2023.101574

Onuoha, F. C., Dimnwobi, S. K., Okere, K. I., & Ekesiobi, C. (2023b). Sustainability burden or boost? examining the effect of public debt on renewable energy consumption in Sub-Saharan Africa. *Energy Sources, Part B: Economics, Planning, and Policy*, 18(1), 1-15. https://doi.org/10.1080/15567249.2023.2214917

Pesaran, M.H. (2004). General diagnostic tests for cross section dependence in panels. Cambridge working papers in Economics Paper No. 0435

Pesaran, M.H. (2007). A simple panel unit root test in the presence of cross-section dependence", Journal of Applied Econometrics, 22, 265-312. https://doi.org/10.1002/jae.951

Rock, M. T., & Angel, D. P. (2007). Grow first, clean up later?: Industrial transformation in East Asia. *Environment: Science and Policy for Sustainable Development*, 49(4), 8-19. https://doi.org/10.3200/envt.49.4.8-19

Shobande, O.A., & Asongu, S.A. (2022). The critical role of education and ICT in promoting environmental sustainability in Eastern and Southern Africa: A panel VAR approach. *Technological Forecasting and Social Change*, 176, 121480. https://doi.org/10.1016/j.techfore.2022.121480

Shobande, O.A. (2023). Rethinking social change: Does the permanent and transitory effects of electricity and solid fuel use predict health outcome in Africa? *Technological Forecasting and Social Change*, 186, 122169. https://doi.org/10.1016/j.techfore.2022.122169

Shobande, O., & Asongu, S. (2023). The dilemmas of relevance: exploring the role of Natural resources and Energy Consumption in managing climate crisis in Africa. *Management of Environmental Quality*. https://doi.org/10.1108/MEQ-01-2023-0025

Steckel, J. C., Hilaire, J., Jakob, M., & Edenhofer, O. (2020). Coal and carbonization in sub-Saharan Africa. *Nature Climate Change*, 10(1), 83-88. https://doi.org/10.1038/s41558-019-0649-8

Sun, J. (1999). The nature of CO2 emission Kuznets curve. *Energy Policy*, 27(12), 691-694. https://doi.org/10.1016/S0301-4215(99)00056-7

Sun, Y., Gao, P., Raza, S. A., & Khan, K. A. (2023). The nonparametric causal effect of sustainable governance structure on energy efficiency and ecological footprint: A pathway to sustainable development. *Gondwana Research*, 121, 383-403. https://doi.org/10.1016/j.gr.2023.05.007

Tarazkar, M.H., Dehbidi, N.K., Ozturk, I., Al-Mulai, U. (2020). The impact of age structure on carbon emission in the Middle East: The panel autoregressive distributed lag approach. *Envir onmental Science and Pollution Research*, 28, 33722-33734. https://doi.org/10.1007/s11356-020-08880-4

Teng, J.Z., Khan, M.K., Khan, M.I., Chishti, M.Z., & Khan, M.O. (2020). Effect of foreign direct investment on CO2 emission with the role of globalization, institutional quality with pooled mean group panel ARDL. *Environmental Science and Pollution Research*, 28, 5271-5282. https://doi.org/10.1007/s11356-020-10823-y

Ugwu, J. N., Nwani, C., Okere, K. I., & Agbanike, T. F. (2022). Regulatory impediments to carbon emission mitigation in Sub-Saharan Africa: the impact of a hostile business environment and high tax burden. *Environmental Science and Pollution Research*, 29(29), 43845-43857. https://doi.org/10.1007/s11356-022-18694-1

United Nations Development Programme (2015). What are the sustainable development goals? https://www.undp.org/sustainable-development-goals

World Bank (2020). World development indicators. World Bank, Washington, D.C.

Yahong, W., Cai, Y., Khan, S. & Chandio, A.A. (2023). How do clean fuels and technology-based energy poverty affect carbon emissions? New evidence from eighteen developing countries. *Environmental Science and Pollution Research*, 30, 37396-37414 https://doi.org/10.1007/s11356-022-24798-5

Yang, B., Ali, M., Hashmi, S.H., & Jahanger, A. (2022). Do income inequality and institutional quality affect co2 emissions in developing economies?. *Environmental Science and Pollution Research*, 29, 42720-42741. https://doi.org/10.1007/s11356-021-18278-5

Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. *Renewable and Sustainable Energy Reviews*, 58, 943-951. https://doi.org/10.1016/j.rser.2015.12.226

Zhang, J., Liu, Y., Saqib, N., & Kamran, H.W. (2022). An empirical study on the impact of energy poverty on carbon intensity of the construction industry: Moderating role of technological innovation. *Frontiers in Environmental Science*, 10, 1-14. https://doi.org/10.3389/fenvs.2022.929939

Zhao, J., Jiang, Q., Dong, X., & Dong, K. (2021). Assessing energy poverty and its effect on CO2 emissions: The case of China. *Energy Economics*, 97, 1-15. https://doi.org/10.1016/j.eneco.2021.105191

Appendix 1: List of Countries

Angola, Benin, Botswana, Burkina Faso, Cabo Verde, Cameroon, Central Africa Republic, Congo Republic, Cote d'Ivoire, Eritrea, Eswatini, Ethiopia, Gabon, Ghana, Guinea, Kenya, Lesotho, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe

Appendix 2. Data summary

Variable	Definition	Unit	Data source
EP1	Access to electricity (Energy povert y 1)	% of the population	World Bank (2020)
EPP2	Access to electricity, urban (Energy poverty 2)	% of urban population	World Bank (2020)
EP3	Access to electricity, rural (Energy poverty 3)	% of rural population	World Bank (2020)
EP4	Access to clean fuels and technologies for cooking (Energy poverty 4)	% of the population	World Bank (2020)
EP5	Renewable energy consumption (Energy poverty 5)	% of total final energy consumption	World Bank (2020)
EP6	Renewable electricity output (Energy poverty 6)	% of total electricity output	World Bank (2020)
EPINDE X	Energy Poverty Index	Authors computation using PCA	Authors computation
GVT	Government effectiveness	Ranges from -2.5 to 2.5	WGI (2020)
RQ	Regulatory quality	Ranges from -2.5 to 2.5	WGI (2020)
EF	Ecological footprint	Gha	Global Footprint Network Database
GDP	Gross Domestic Product Per Capita	Constant 2010 US$	World Bank (2020)
URB	Urbanization	% of total population)	World Bank (2020)

Source: Authors Computation