Clean Energy Access, Renewable Energy Consumption and Environmental Sustainability: An Impact Analysis for Sub-Sahara African Countries

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Abstract
This study investigates the impact of clean energy access (EA) and renewable energy consumption (REC) on environmental sustainability in Sub-Saharan African (SSA) countries using secondary data from 48 SSA countries from 2016–2022. The system GMM estimation technique was adopted in this study. The results show that both EA and REC significantly reduces environmental sustainability, indicating that increasing the use of renewable energy and expanding access to clean energy can effectively reduce carbon emissions (CO2) in the region. The study suggests improving energy access and renewable energy utilization by putting supportive policies into place and investing in local capacity building for the planning, design, installation, and maintenance of renewable energy systems.

Keywords: Clean Energy Access, Renewable Energy Consumption, Environmental Sustainability, Sub-Saharan Africa, System GMM

***JEL Classification*:** Q50, Q54, Q56.

Introduction
Economic growth and development are critical goals for many countries, typically driven by industrialization, which often leads to increased CO_2 emissions. Emissions, predominantly from the use of fossil fuels for energy production, represent a significant driver of global warming and contribute extensively to environmental degradation. As the world strives to meet sustainable development goals (SDGs), including poverty reduction, inclusive societies, and environmental protection, reducing CO_2 emissions has become a global priority (Burke, Hsiang, & Miguel, 2015). Globally, CO_2 emissions from fossil fuel combustion amount to approximately 34 billion tonnes per year, mainly from coal (45%), oil (35%), and gas (20%) (International Renewable Energy Agency [IRENA], 2020). The rise in emissions since 1970 is predominantly due to industrial processes and energy

production. Regions like Asia Pacific are the largest emitters due to extensive industrial activities, particularly in China and India, which rely heavily on coal. Conversely, Africa contributes only about 2.4% of global emissions, but this is increasing exponentially as a result of increase in population and urbanization. Moreover, SSA's CO_2 output per person has been growing fast (increased by a factor of 14 from 1950 to 2016)—much faster than its population. SSA projected population is 3 billion by 2060 (International Energy Agency [IEA], 2021), with 5.8 gigatonnes of CO_2 per year. Despite SSA contributing less than 3% of global CO_2, per captia CO_2 increased by 86.6% from 2000 to 2019.

Energy, essential for production and economic growth, is increasingly in demand as the population grows, urbanizes, and income levels rise. Energy sources are categorized into nonrenewable (fossil fuels and nuclear) and renewable (solar, wind, hydro, biomass, and geothermal). Nonrenewable sources are limited and contribute significantly to CO_2 emissions, while renewable sources offer cleaner alternatives with minimal environmental impact. Africa's renewable energy resources are abundant, including over 1.1 million GWh of hydro capacity, significant geothermal potential, and vast reserves of solar and wind energy. However, SSA remains the least electrified region globally, with only 48% of its population having access to electricity and 17% to clean cooking facilities. Despite low contribution to global emissions, emissions in Africa have increased by 86.6% from 2000 to 2019, and this trajectory is anticipated to persist, with projections of reaching 5.8 gigatonnes per year by 2060—comparable to current emissions levels in the United States (IRENA, 2021). Moreover, access to *CE* is a critical determinant of environmental sustainability, particularly in SSA, where traditional biomass fuels like firewood and charcoal dominate household energy consumption. The reliance on these fuels contributes to environmental degradation, including deforestation, biodiversity loss, and increased carbon emissions.

The study is carried out to examine the extent to which *CE* and *REC* impact environmental sustainability in SSA, with a specific focus on reducing CO_2 emissions. Despite the abundance of renewable energy (*RE)* resources in the SSA region, limited investment and financial limitations is hampering the growth of *RE* projects. In order to ensure inclusive growth without hampering prosperity of the future generation, it is imperative to promote the expansion of *RE*, especially off-grid options (Belaid & Youssef, 2017; Lee, 2019). The effective and efficient use of available *RE* resources in the region would largely reduce reliance on fossil fuels, which will help to lower CO2 emissions and promote compliance with international climate goals.

The attempt to address the problems of CO2 emissions in SSA is highlighted by international frameworks such as the 2015 Paris Agreement, the European Union's (EU) target and the United Nation's (UN) Sustainable Development Goals (SDGs). While the Paris Agreement aims to limit the global temperature increase to below 2 degree Celsius by 2030, the EU aim at reducing greenhouse gas emissions by at least 55% in 2030, 90% in 2040, and climate neutrality by 2050. Achieving this target requires more deliberate attempt to shift away from fossil fuels use to *RE* sources, which is also in line with the SGDs that promote sustainable development and environmental quality.

Literature Review

Conceptual Review

According to the World Bank (2024), energy access is the extent at which people and industries have access to consistent and reliable energy resources needed for domestic and operational needs. This encompasses access to reliable and uninterrupted energy resources like electricity, natural gas, and other energy forms that is required for industrial processes. This does not exclude the use of clean and *RE* sources, such as solar, wind, hydropower, and biomass. According to WDI 'the percentage of people that primarily uses clean cooking technologies and fuels is a measure of access to clean cooking fuels, with kerosene not meeting WHO's clean cooking fuels criteria".

REC depicts the use of energy that is gotten from natural resources, and which are either inexhaustible or replenish naturally and faster than they are consumed (IEA, 2021). The definitions and interpretations of *RE* vary among organizations and scholars. According to IRENA (2013), renewable energy encompasses all energy generated sustainably from renewable sources. Similarly, the European Union (Eurostat, 2021) and UNEP (Frankfurt School, 2018) aligns with the previous perspective in recognizing similar renewable energy sources.

From scholarly perspectives, Sarkodi and Owusu (2016) emphasize renewable energy as sources that naturally replenish without depletion. Inglesi-Lotz (2016) views renewable energy as a viable solution for mitigating greenhouse gas (GHG) emissions while supporting economic growth and environmental sustainability. Grabara et al. (2021) define renewable energy as energy from naturally renewable sources. A common thread across definitions is the emphasis on sustainability, where renewable energy must be produced in ways that do not compromise the environment or deplete resources. Renewable energy is often juxtaposed with fossil fuels, which are finite and non-renewable within human timescales. Key *RE* sources consistently include solar, wind, hydro, geothermal, and bioenergy, with some definitions extending to ocean energy (tidal and wave) and renewable components of waste. For this analysis, *REC* is defined as the utilization of energy from relatively naturally replenishable sources. These include solar, wind, hydro, bioenergy, and geothermal energy, and estimated as the proportion of *REC* from total energy consumption in SSA.

Environmental sustainability refers to the ability of natural systems to endure and support life while ensuring ecological balance and minimizing the adverse impacts of human activities. CO2 emissions are a commonly used indicator to evaluate environmental sustainability as highlighted by Saboori et al. (2012), Chen and Lei (2018), and Sakodie et al. (2020), among others. Urbanization, energy use, deforestation, and industrial operations, has been identified has some of its major causes.

Theoretical Review

The Environmental Kuznets Curve (EKC) hypothesis and the substitution hypothesis are some of the frequently used theories used to explore the relationship between energy types and environmental sustainability. The former was named after Simon Kuznets, and suggests that as economies progress, environmental quality deteriorates up to a specific income threshold, after which it improves as income levels continue to increase. This model has been used to explain how different stages of economic development affect CO2 emissions (Shahbaz et al., 2013; Mert & Boluk, 2016; Naz et al., 2019).

Whereas the substitution hypothesis highlighted that increased use of *RE* can reduce nonrenewable energy (*NRE*) consumption, such as fossil fuel, coal, and gas. It further posits that increasing use of *RE* sources will indirectly reduce CO2 emissions, due to the lower use on *NRE* which are carbon-intensive energy sources. This hypothesis proposed for the replacement of conventional, carbon-intensive energy sources with *RE* technology (Liu, Wang & Wang, 2023), which would invariably increase energy efficiency and enhance reduction in CO2 emissions (Lin & Abudu, 2020).

Empirical Review

Studies on the relationship between energy access, *REC* and CO2 emissions across different countries and regions have found mixed results, which shows how inconsistent the relationship could be. A majority have shown that *REC* leads to reductions in environmental degradation (Shafiei & Salim, 2014; Dogan & Seker, 2016; Wang et al., 2023b), while the findings of some suggests existence of a positive or none significant association (Apergis et al., 2010; Menyah & Wolde-Rufael, 2010), often attributed to low adoption level of *RE* in certain regions.

The dynamic relationship between economic prosperity and carbon emissions has been supported by numerous researches conducted with the adoption of the EKC framework (Dong et al., 2018). Yet, the findings of other researches do not concur to the framework's proposition (Inglesi-Lotz & Dogan, 2018; Mikayilov et al., 2018). Among the causes of disparities in findings could be due to varying sample selection, economic structures, and stages of development of the countries and regions observed. The relationship between *REC* and environmental sustainability is becoming important in SSA in recent times, as the region seeks sustainable growth paths. For example, studies have shown that the increase in Ghana's hydropower production, as well as South Africa's and Kenya's capacity for *RE* is associated to reduced CO2 emissions (Twerefou & Acheampong, 2019; Mashela & Tang, 2017). Notwithstanding, series of factors have been identified to be hindering the widespread adoption of *RE* in SSA countries, to include inadequate infrastructural facilities, financial constraints, and policies inconsistency (Ding et al., 2020). Some studies suggest that the impact of *RE* on CO2 emissions may vary based on the composition of the energy resources (Sarkodie & Adams, 2018), while some proposed that effect of different *RE* sources on CO2 emissions vary across countries in SSA (Lotz & Dogan, 2018).

Despite a general perception about the beneficial effect of *RE* on environmental sustainability, through reducing CO2, the relationship remains unclear. For example, it has been discovered in SSA that the use of biomass (charcoal and wood) as a *RE* source has generated concerns about energy waste and deforestation, which can eliminate the benefits of other *RE* sources with lower emissions (Kammen & Lew, 2019). In addition, studies have shown that the extent of the relationship between *REC* and CO2 emissions could rely on the quality and effectiveness of governance, as well as energy policies implemented (Wang et al., 2023a). More studies for insightful understanding of how SSA could achieve sustainable energy access and notable CO2 emissions reductions can be achieved through inquiries into the roles of policies on environmental sustainability.

Research Methodology

In this study, the EKC and the substitution hypothesis are adopted to explore how clean energy access and *REC* impact CO2 emissions in SSA. Some studies have incorporated these hypotheses in explaining the relationship between economic variables, which includes the relationship between *REC* and CO2 emissions (Littwin, 2009; Saidi & Omri, 2020). This study adapts the model proposed and used by researchers in previous studies while examining the relationship between different energy sources and environmental sustainability (Saboori et al., 2012; Rahman, 2017). The modified model is as follows:

$$ES = (EA, REC) \tag{1}$$

where ES is environmental degradation; EA is clean energy access; and REC is renewable energy consumption. The model can be expressed in econometric form as follows, to incorporate control variables:

$$ES_{it} = \alpha_{0j} + \alpha_{1j}ES_{2it-1} + \alpha_{2j}EA_{it} + \alpha_{3j}REC_{it} + \alpha_{4j}IND_{it} + \alpha_{5j}EP_{it} + \vartheta_t + \chi_i + \varepsilon_{it} \tag{3}$$

Where *ES* represents carbon dioxide emissions, estimated in metric tons, while ES_{it-1} represents the lag of carbon dioxide emissions, included to account for the dynamic nature of the model. *IND* stands for industrialization, measured as the percentage of industrial value added in *GDP*, while the other symbols remain the same. *EP* represents environmental sustainability policies and institutions, which evaluate the effectiveness of environmental policies in promoting the protection and sustainable use of natural resources as well as pollution management, rated on a scale from 1 (low effectiveness) to 6 (high effectiveness). This variable evaluates the policy framework on environmental sustainability and is included in the model to determine its potential to enhance sustainable development in SSA countries. The subscripts *i* and *t* represent the country (48) and time period (7 years), respectively; ϑ_t is the time-specific effect; χ_i is the country-specific effect; εit is the stochastic error term that represents all other variables affecting environmental sustainability in SSA but not included in the model. Moreover, α_{0j} is constant, α_{1j}, α_{2j}, α_{3j}, α_{4j}, and α_{5j} represent the coefficient elasticities of the explanatory variables with respect to ES.

Table 1: Variable Description

Variables	Notation	Description	Sources
Environmental sustainability	*ES*	Total carbon emissions produced from energy consumption.	WDI
Clean energy access	*EA*	Percentage of population primarily using clean fuels and technologies for cooking	WDI
Renewable energy consumption	*REC*	Percentage of renewable energy consumption from total energy use	WDI
Industrialisation	*IND*	Level of production and value generated by industrial activities	WDI
Environmental policies	*EP*	Policies and institutions on environmental sustainability	WDI

WDI is World Development Indicators (2023)

The model's core independent variables are renewable energy consumption (*REC*) and access to clean fuels (*EA*), with environmental sustainability (*ES*) as the dependent variable. Industrialization and environmental policies serve as control variables. Carbon emissions (*ES*) are expressed in metric tons and converted into logarithmic form to mitigate data skewness. The explanatory variables (*REC, EA*, and *IND*) are in percentages, and EP is rated on a scale from 1 to 6. Secondary data is used in this study, all of which are obtained from the World Bank, WDI. The annual panel data covers the 2016 to 2022 period. The data used in this study is analysed using the System Generalized Method of Moments (GMM) panel-data estimation technique, which controls for country-specific effects while preserving the cross-country data dimension (Anderson & Hsiao, 1981; Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell & Bond, 1998).

Results Presentation and Discussions

The obtained data was analysed using the STATA version 17.0 software. The descriptive statistics is presented in table 1. As shown in the descriptive statistics table, the mean value is higher than the standard deviation of all variables except the *EA* variable. The correlation relationship among the variables is also shown in table 3. The result suggests absence of strong correlation among the variables, with correlating values ranging from -0.4334 to 0.5837. This also suggest the absence of multicollinearity in the model.

Table 2: Descriptive Statistics

Variables	Observations	Mean	Std. dev.	Min	Max
ES	322	23.28414	1.462799	19.66049	26.89159
EA	288	23.6526	28.77554	0	100
REC	263	62.50544	26.64768	1.21	97.03
IND	308	24.78378	10.603	4.871401	57.3954
EP	271	3.223247	.670112	1	4.5

Source: Authors' Computation via STATA 17.0

Table 3: Correlation Matrix Result

	ES	*L.ES*	*REC*	*EA*	*IND*	*EP*
ES	1.0000					
L.ES	0.9981	1.0000				
REC	-0.1105	-0.1042	1.0000			
EA	-0.4322	-0.4326	0.5837	1.0000		
IND	0.3443	0.3478	0.0067	0.0145	1.0000	
EP	0.3765	0.3710	-0.4334	0.1651	-0.1834	1.0000

Source: Authors' Computation via STATA 17.0

The result of the estimated model is presented in table 4 below, and shows the relationship between energy access, *REC*, and CO2 in SSA. As shown in the table *REC*, and access to clean energy have significant associated with CO2 emissions. Notably, access to clean energy demonstrates a negative and significant association with CO2 emissions, with result suggesting that a 1% increase in clean energy access will lead to about 0.11% reduction in CO2 emissions. Similar to this is the observed negative significant relationship between *REC* shows and CO2 emissions, where a 1% increase in *REC* corresponds to about 0.13% reduction in CO2 emissions. These results indicates that *REC* has greater impact on CO2 emissions compared to access to clean energy in SSA. In addition, the result shows that environmental policies also have a negative and significant association with CO2 emissions, implying that effective environmental policies is beneficial to reduce emissions in SSA.

Table 4: The Impact of Energy Access and Renewable Energy Consumption on Carbon Emission in SSA (Dep. Var.: ES. LOG)

Variables	System GMM	Difference GMM
L.ES	1.01025***(80.35)	0.92342***(0.18)
EA	-0.0011174*(-1.77)	-0.0380479*(0.47)
REC	-0.0012889*(-1.88)	-0.0620072**(-2.05)
Control Variables		
IND	0.000992(0.80)	0.0047728(0.28)
EP	-0.0051302*(-0.35)	1.198976*(0.92)
Observations	135	135
F Statistic	309811.75	532175.44
Diagnostic tests		
No of Groups	36	45
No of Instruments	26	7
AR (s) p-value	0.782	0.687
Hansen: p-value	0.213	0.218

Source: Authors' Computation via STATA 17.0

The results presented suggest that industrialization have an insignificant positive association with CO2 emissions, implying that perhaps the contribution of industrial activities to environmental degradation in SSA is not significant. While the diagnostic tests for autocorrelation and instrument selection confirm the model's robustness, showing no second-order autocorrelation (AR(2); p-value = 0.782), the Hansen statistic test for instrument validity (p-value = 0.213) further supports that the exogenous instruments in the model are correctly specified. Moreover, the results from the difference GMM estimation are consistent with those from the system GMM, as shown in Table 4, affirming the reliability of the findings.

These results suggest that *REC*, clean energy access, and environmental sustainability policies are negatively and significantly associated with CO2 emissions in SSA. The findings align with the hypothesis that increasing clean energy access and promoting renewable energy use can effectively reduce carbon emissions, enhancing a sustainable environment in SSA. This conclusion supports previous study by Badeeb, Lean and Clark (2017), Sarkodie, Adams and Leirvik (2020), and Wang et al. (2023a). The observed negative relationship between environmental policies and CO2 emissions emphasizes the importance of robust policies and institutions in promoting environmental quality. It suggests that SSA governments should develop and implement integrated environmental policies addressing multiple sustainability dimensions. Conversely, the positive but insignificant relationship between industrialization and CO2 emissions suggests that despite industrial activities' potential to increase emissions, their environmental impact in SSA is negligible. To mitigate industrialization's potential environmental effects, implementing energy-efficient technologies and practices in industrial processes is recommended. SSA countries can achieve this by seeking international support and partnerships for sustainable industrialization, including collaboration with developed nations and international organizations to facilitate technology transfer, funding for clean energy projects, and knowledge exchange.

Robustness checks were further conducted by performing additional estimations and examining the interaction between *REC* and environmental policy on CO2 emissions. This further validated the estimated results. The estimates indicate dynamic relationships among variables in the respective models, with consistent associations between core explanatory variables and the dependent variable, albeit with minor discrepancies in significance levels and coefficients. The interaction of renewable energy and environmental policy reported a negative and statistically significant impact on CO2 emissions in SSA, reinforcing the findings.

Table 4: Robustness Check (Dep. Var.: ES, LOG)

Variables	System GMM	Pooled OLS	Fixed Effect	Random Effect
L.ES	0.959036*** (4.27)			
EA		-0.0007**(-2.28)	0.0084046* (1.53)	-0.0007078** (-1.48)
REC		-0.00004*(-0.11)	0.024042*** (-6.64)	-0.0000855* (-0.17)
REC*EP	-0.00590**(1.41)			
Control Variables				
IND	0.039091 (0.36)	-0.00004(-0.05)	0.0002184 (0.13)	0.0005762 (0.58)
EP	0.0010293* (-0.52)	0.009(1.11)	-0.0397972* (-0.73)	0.0113428 (0.81)
Observations	135	135	135	135
F Statistic	309811.75			532175.44
Diagnostic tests				
No of Groups	39			
No of Instruments	16			
AR (2) p-value	0.399			
Hansen: p-value	0.195			
Prob > F		0.0000	0.0000	
Prob > chi2				0.0000
R-squared		0.9973	0.2970	0.9972
Hausman P			0.0000	

Source: Authors' Computation via STATA 17.0

Conclusion and Policy Recommendations

An attempt is made in this study to explore the effects of energy access and *REC* on CO2 emissions in SSA countries. The was discovered that both REC and access to clean energy significantly reduce CO2 emissions in SSA. In addition, the result revealed that policies and institutions on environmental sustainability is significant in reducing CO2 emissions. The findings of this study suggest that intensifying access to clean energy, increasing *REC*, and implementing effective environmental policies can to a large extent promote environmental sustainability in SSA. The results also support the argument that investments in *RE* resources and is conducive for environmental sustainability in SSA. In this light, transitioning to *RE* sources and urgent need for intensive access to clean energy is proposed as a pathway to substantial environmental sustainability.

This study also proposes, that Governments in SSA countries should prioritize policies that would enhance widespread access to clean energy, and encourage *RE* use, which includes intensive investment in *RE* infrastructure, and giving incentives to encourage private sector involvement through subsidies, tax benefits, and favorable regulations. Governments in SSA countries should also champion efforts on public awareness of both the environmental and economic benefits of clean energy use, with the motive of increasing its adoption. In addition, there is need for regional cooperation in the region, especially in the area information exchange, technology transfer, capacity-building programs and resource mobilization to hasten the transition to *RE*. Moreso, governments can achieve environmental sustainability by adopting and implementing policies aimed at reducing CO2 emissions like carbon pricing, giving incentives for investments in energy-efficient technologies, and strengthening the institutions that are in custody of upholding environmental laws.

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