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Energy consumption-economic growth nexus: How does sectorial differentials affects sustainable development?

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Abstract

Energy, being one of the significant drivers of growth, has gained much focus in the last four decades. A connection between energy and growth exists in the economy: on the one hand, energy is a vital factor of production while growth improves living standards, which increases energy consumption on the other hand. Previous studies on the energy-growth nexus paid less attention to sectorial differentials in the consumption of energy and growth. Also, the literature could not relate that to sustainable development. Thus, this study explores the sectorial differentials in energy consumption and how they affect the energy-growth nexus within the context of sustainable development. The research employed secondary data for 46 sub-Saharan Africa (SSA) countries for the period 2007 to 2020. Using the General Methods of Moments estimation technique, we found that all the measures of energy consumption positively affect economic growth. Also, CO₂ intensity is positively related to growth in the economy while CO₂ emissions from solid fuels negatively affect economic growth. Again, Foreign Direct Investment (FDI) is positively impacting economic growth and Gross Domestic Product (SSA) per energy use. Policy implications are discussed in the paper.

KEYWORDS

energy-growth nexus, GMM, sectorial energy consumption, SSA, sustainable development

1 | INTRODUCTION

Energy is the “backbone” of an economy if such an economy wants to achieve growth and development. As an economy grows and develops the output mix of the economy changes (D. I. Stern & Cleveland, 2004), economic growth goes with industrialization which calls for greater energy consumption both in industries and households. If policy constraint influences the energy supply, economic development is harmed. Energy and capital are at top weak substitutes and perhaps complements in industrialization drive and growth attainment. Industrialization is achieved with both the presence of capital and the availability of sufficient energy for the production of consumer goods.

In Africa, just like other regions, the energy sector is vital to its process of economic growth; however, globally, Africa's energy sector is part of the most wrongly understood system of energy (African Energy Outlook-AEO, 2014). The growing significance of climate change issues and the quest for introducing ways to reduce greenhouse gases while attaining sustainable growth has taken focus in the energy-growth literature. Using conservative energy from sources of fossil fuels like natural gas, coal, and petroleum has been recognized as the key determinant of greenhouse gases that pave the way for global warming (Maji et al., 2019). Africa is found to be highly dependent on unsustainable biomass fuels for home use (Karakara et al., 2021; Karakara & Dasmani, 2019; Karakara & Osabuohien, 2020) and have in most case low economic growth or no inclusive growth (Karakara & Osabuohien, 2021). Such high dependence on biomass fuels depletes forest resources and causes long-term effects of environmental destruction. Thus, household energy consumption type has implications for an environmentally benign society.

Aside household energy consumption mixes and their implications for environmental issues, the industrial energy consumption mix causes similar concerns. Industrial energy is said to be one of the leading greenhouse gas emitters (Li et al., 2021). As industrialization strives growth in the economy is expected to be achieved. Such industrialization drive calls for more energy consumption (Cetin & Seker, 2012). Thus, the energy consumption mixes in both the industrial and household sectors would have a variant effect on the economy as well as the environment. In the energy-growth literature, studies have majorly looked at the consumption of energy and growth (with GDP as the main measure) on one hand and the other hand has studied the kind of energy consumption and sustainable development. However, studies have neglected how each sector's (household or industrial) energy consumption cum its contribution to greenhouse gas affects sustainable development. For instance, Kargi (2014) found bidirectional causality between GDP and residential consumption of electricity and GDP and industrial electricity consumption based on data in Turkey from 1970 to 2010. Morimoto and Hope (2001) also asserted that current as well as previous variations in the supply of electricity significantly impact the change in real GDP in Sri Lanka. Kasperowicz (2014) detected that consumption of energy has a positive association with economic growth based on data from the Eurostat databases for 12 European countries from the period 2000 to 2012.

Energy is a key component of production (Osei et al., 2023; Pokrovski, 2003; D. A. Stern, 2000), and economic expansion raises living standards, which in turn leads to a rise in energy consumption. The literature on the association between the use of energy and growth in the economy is the result of numerous research, the results of which have been inconsistent or even contradictory due to the use of various measurements of energy use. It makes sense to believe that different energy consumption measurements could have different effects on growth and vice versa. For instance, due to the alternative cost idea, which states that residential energy consumption prevents the use of energy in the industrial sector, it would provide more value added. Household and industry consumption of energy may not have a similar influence on growth. As a result, it stands to reason that household energy use may have a minimal or no effect on growth in the economy.

In another breadth of the literature, scholars indicated that the energy consumption mix directly affects the environment. Maji et al. (2019) summarized that the kind, as well as the renewable energy source employed in West Africa, which is mostly wood biomass, has affected both growth and environmental sustainability. While Li et al. (2021) confirmed that economic growth enhances CO₂ emissions and Balsalobre-Lorente et al. (2022) discovered that an inverted-U-shaped association exists between complexity in the economy and CO₂ emissions, and further, an N-shaped relationship for countries like Ireland, Spain, Greece, Italy, Spain, and Portugal. Apergis et al. (2010) maintained that the type of energy consumption (nuclear energy in their case) has a significant role in minimizing CO₂ emissions. Gabr and Mohamed (2020) explain that energy consumption, which is predominantly accountable for greenhouse gas (GHG) emissions, primarily CO₂, is a driver of economic growth. A by-product of sources of main consumption of nonrenewable energy, like as fossil fuels, is CO₂ emissions. According to Irfan et al. (2021), certain nations have largely switched to sources of renewable energy, thus fossil fuels are no more based on sources of non-renewable energy.

In different ways, this study contributes to the energy consumption-economic growth literature: first, it has considered the sectorial contributions to the consumption of energy and growth, and thus, it is one of the pioneered types of research on sectorial differences in the energy consumption-growth nexus effect on sustainable development. To this effect, we looked at how much residential energy consumption or industrial energy consumption contributes to CO₂ emissions and subsequently sustainable development. Does industrial energy consumption contribute more to CO₂ than residential energy consumption? Second, the study used the most current annual data including the year 2020. The use of current data will give results that are up to date in the energy consumption-growth studies. Third, this paper focused on SSA as earlier studies were on developed countries. We focused on SSA for the reason that the region has developing countries and there is a need for an understanding of their energy-growth nature. Again, the region (SSA) has the highest biomass consumption (IEA, 2018) and slow economic growth coupled with underdeveloped nature, hence the need to study their energy-growth nexus for policy making. Finally, a robust check was done on the results generated. The key variables in the study include: economic growth (GDP growth), access to electricity, CO₂ intensity, GDP per unit of energy use, emissions of CO₂ from residential buildings, CO₂ emissions from industry, and control variables such as regional dummy and FDI.

The remainder of the paper is organized as follows: next to the introduction is section two, which reviews theoretical and empirical literature. This is followed by data and methodology in the third section. Section four gives the discussion of results, and section five concludes.

2 | THEORETICAL AND EMPIRICAL LITERATURE

The energy and output nexus has two competing views. Energy has a minimal impact on output as it has a very minor share in creating value addition according to the neoclassical approach. Growth concepts, like the Solow-Swan models and Harrod Domar, even contend that energy cannot be seen as a component of a production function (Camarero et al., 2015). Nevertheless, notwithstanding the assumptions made in the neoclassical concepts, models of internal growth of public spending (Barro, 1988), as well as human capital (Lucas, 1988) both with the contributions of the neoclassical economists of Hamilton (1983), have proved that energy could be a vital element of production. Likewise, economists stress that energy is a key production factor (D. I. Stern, 1997). Industrialization along with growing investment in infrastructure leads to high and constant consumption of energy. A cumulative volume and function of the energy in production within the industry qualify it to be one of the crucial inputs together with capital and labor. In the technological process, it can even serve as a substitute for the labor force (Ghali & El-Sakka, 2004).

In the energy-growth nexus literature, four contesting hypotheses exist, and each is built on theoretical postulations. One such hypothesis is the hypothesis of growth, which asserts that connection runs from energy to growth. Hence, any fall in the consumption of energy due to government policies or market constraints will affect economic

growth negatively (Akinlo, 2008). Another strand of the energy-growth nexus hypothesis is the conservation hypothesis, which is in contrast with the growth hypothesis. The hypothesis of conservation underlines that growth is the key reason for the consumption of energy and in this sense; growth in the economy will enhance the consumption of energy (Asafu-Adjaye, 2000). The third hand of literature is referred to as the feedback hypothesis, which maintains that the energy-growth nexus is a bidirectional causality: consumption of energy influences growth and vice versa (Al-Iriani, 2006). Lastly, no underlying connection exists between energy consumption and growth according to the neutrality hypothesis (Bozoklu & Yilanci, 2013).

Energy consumption and growth have also been the subject of empirical investigations. According to research by Abid and Sebri (2012), energy use is not a determinant of Tunisian economic growth, nor is the energy sector a growth constraint. They also discovered a short-run, unidirectional Granger causation connecting energy usage and industrial value addition. These results support the main hypothesis of demand modeling, which states that knowledge of historical industrial production values influences predictions of energy consumption and that domestic energy use levels are positively influenced by household income.

Hasanov et al. (2017) studied the energy-growth association using 10 oil-exporting Eurasian countries: Azerbaijan, Kazakhstan, Bahrain, Oman, Kuwait, Iran, UAE, Saudi Arabia Qatar, and Russia, for the period 1997–2014. A panel cointegration, and the Granger causality test. Employing different methods and measures of energy consumption, the authors found that primary energy consumption affects growth in the economy. However, they found no significant association between economic growth and residential electricity consumption, either in the short run or long run confirming the neutrality hypothesis. They further said that employment and FDI are the major drivers of growth in the countries selected. Antonakakis et al. (2017) examined the dynamic relationship between economic growth, energy consumption, and environmental degradation in 106 countries over the period 1971–2011, and the Panel Data Vector Autoregressive (PVAR) was used. The results showed the existence of a bidirectional nexus between economic growth and energy consumption.

In a multivariate approach, Ucan et al. (2014) studied the association between renewable and nonrenewable energy use and economic growth for 15 nations in the European Union from 1990 to 2011. A long-run equilibrium link between GDP, consumption of energy, greenhouse gas emissions, research, and development were found using the heterogeneous panel cointegration tests. However, the author concluded that there exists unidirectional causation between nonrenewable energy use and economic growth in the analyzed countries by applying the Granger causality approach.

Ahad et al. (2021) studied the impact of the shadow economy on renewable and nonrenewable energy consumption at aggregated and disaggregated levels over the period of the first quarter of 1972 to the fourth quarter of 2018 in Pakistan. They employed nonlinear/asymmetric time series analysis, quantile unit root test for stationary data series, quantile cointegration for the existence of long-run relationships, and quantile causality approach to identify the direction of causality over the quantiles. The results confirm that quantiles of the shadow economy cointegrate with the quantiles of energy consumption at aggregated and disaggregated levels. The results of quantile regression show that a shadow economy has a positive and significant impact on renewable and nonrenewable energy consumption at aggregated and disaggregated levels in all quantiles starting from extremely low quantiles to extremely high quantiles. Furthermore, the results of quantile causality illustrate a unidirectional causality running from underground economy to fluctuations in renewable, nonrenewable, and total energy consumption. More specifically, disaggregated energy consumptions such as oil, gas, nuclear, hydro, and gas are also caused by the shadow economy, generally in low and high tails/quantiles.

Menegaki and Ozturk (2013) uses a multivariate panel framework to look at the association between growth and renewable energy in 27 European nations. For the period 1997 to 2007, employment and greenhouse gas emissions are additional variables in this multivariate panel framework. The finding supports the neutrality hypothesis. In their study of the correlation between the generation of electricity from renewable sources and the development level for 154 countries, Kazar and Kazar (2014) substitute the development level for the economic growth variable. The study's findings indicate that while in the long-run economic growth outpaces the supply of renewable energy,

there is a short-term bidirectional relationship between the two. Additionally, this relationship fluctuates depending on the level of human development of the nation.

For 19 industrialized and developing nations between 1984 and 2007, Apergis et al. (2010) investigated the association between emissions of CO₂, nuclear energy usage, growth, and consumption of renewable energy. The findings show that there is a bidirectional causal relationship between the use of renewable energy and economic growth, supporting the feedback hypothesis. Nuclear energy also plays a significant role in lowering CO₂ emissions. Additionally, for the period 1995 to 2014, Maji et al. (2019) made use of a panel dynamic ordinary least squares (DOLS) in examining the effect of renewable energy on growth in 15 West African nations. Their findings suggested that renewable energy usage in these nations inhibits economic growth.

Li et al. (2021) investigated the connection between economic development, energy use, and emissions of carbon in G20 nations from 1992 to 2014. The authors confirmed that economic expansion is a key factor in the promotion of CO₂ emissions in the G20 countries under study using the Common Correlated Effects Mean Group (CCEMG) estimate. As a result, countries' CO₂ emissions increased due to increased consumption of energy. Urbanization increased CO₂ emissions in the countries, and FDI fueled this trend. Additionally, Odugbesan and Ryoub (2020) looked at the connections between urbanization, energy use, CO₂ emissions, and economic growth in the MINT (Mexico, Indonesia, Nigeria, and Turkey) nations. Using annual data from 1993 to 2017 and the ARDL Bounds test methodology, the authors discovered that Turkey, as well as Mexico, underwent the feedback hypothesis, which suggests a bidirectional relationship, while Nigeria and Indonesia supported the energy-growth hypothesis, which suggested unidirectional causality from energy consumption. At the same time, all of the MINT countries are experiencing a long-term association between urbanization and economic development, consumption of energy, and emission of CO₂.

Ahad et al. (2022) explored the energy-growth nexus in the presence of an underground economy for Pakistan. They employed the combined cointegration method and then apply a vector error correction model. The results reveal that official GDP, underground economy, and true GDP positively and significantly affect energy consumption in both the short and long run. Similarly, financial development as well as foreign direct investment enhance energy consumption. The authors find unidirectional causality between energy consumption and official GDP variables, underground economy and energy consumption in the long run, and a bidirectional causality in the short run between energy consumption and official GDP. Again, Fatima et al. (2018) earlier examine the relationships between aggregated and disaggregated energy use in the industrial sector, carbon emissions, and industrial output in China, by employing annual frequency data for the period of 1984–2015. Adopting augmented Dickey–Fuller and Phillips and Perron unit root tests, the Zivot–Andrew structural breaks unit root test, and the autoregressive distributed lag bounds test, they found the existence of a long-run relationship in the presence of structural breaks. They concluded that aggregated and disaggregated energy consumption in the industrial sector increases CO₂ emission in both long and short run. The VECM Granger causality analysis indicates the bidirectional relationships between CO₂ emission, industrial growth, and aggregated and disaggregated (coal, oil, and natural gas) energy consumption.

Furthermore, Kais and Mbarek (2017) studied the dynamic association between CO₂ emissions, growth in energy, and growth in three North African countries over the period 1980–2012. Using the VEC model, the authors pointed out the existence of a unidirectional association between growth in the economy and consumption of energy in those studied countries. Also, Gaspar et al. (2017) evaluated the connection between energy consumption in 20 European nations between 1995 and 2014 using the ISEW to compare a sustainable development method with the conventional economic growth approach. The findings supported the cautious theory of economic growth and energy usage. To better understand the connection between environmental deterioration, consumption of energy, and growth in 26 OECD nations from 1980 to 2010, Özokcu and Özdemir (2017) conducted a study. In the study, the authors used Driscoll–Kraay standard errors and panel data estimation methodologies. The findings showed that in the countries under study, economic growth and energy use are positively correlated.

Cetin et al. (2018) examines the impact of economic growth, energy consumption, trade openness, and financial development on carbon emissions for the case of Turkey by using annual time series data for the period of 1960–2013. They adopted the Lee and Strazicich test applying the bounds testing approach to cointegration and found that there exists a long-run relationship between the per capita real income, per capita energy consumption, trade

openness, financial development, and per capita carbon emissions in the presence of structural breaks. They also found that in the long run, carbon emissions are mainly determined by economic growth, energy consumption, trade openness, and financial development. The VECM Granger causality analysis indicates a long-run unidirectional causality running from economic growth, energy consumption, trade openness, and financial development to carbon emissions.

The above literature reviewed indicates that there is a plethora of studies on energy consumption-growth nexus across the globe. While some of the studies are on single-country cases, others are on a panel of countries. One of the limitations of a single-country study is that they are often hindered by the small sample, which reduces the power of their unit root and cointegration (Streimikiene, 2016). Again, most of the studies connect energy consumption to either growth or CO₂ emissions. Yet, other scholars studied the case of specific energy consumption (renewable energy) and growth and environmental destruction. There are few studies on the specific case of energy consumption-growth nexus and its implications for sustainable development. Again, we have not come across a case where scholar(s) studied the contribution of industrial and residential energy consumption to growth and sustainable development. Thus, we studied the case of sector differences in energy consumption and sustainable development in SSA countries.

3 | DATA AND METHODOLOGY

3.1 | Data

The study employed secondary data for 46 SSA countries for the period 2007–2020. The countries selected (see list in Appendix B) and the years used were solely based on data availability on the variables of interest in the study. All variables used (aside from the regional status of the countries) were obtained from the World Development Indicators (WDI). They include GDP growth, GDP per unit of energy use, Energy use, Access to electricity, Foreign Direct Investment-FDI, CO₂ intensity, CO₂ emissions from residential buildings, CO₂ emissions from manufacturing industries, CO₂ emissions from solid fuel, CO₂ emissions from liquid fuel, and sub-regional status of the countries.

Economic growth was captured as the real GDP in US dollars at constant 2011 prices. FDI is a key driver of growth in developing countries. FDI could turn out to be detrimental or increase emissions of CO₂ if there are slack environmental controls in the countries that allow the operation of highly polluting industries (Li et al., 2021). The variables and their description are presented in Table 1.

3.1.1 | Trend of the variables of the study

This section dwells on trend analysis of the key variables over the years in comparison with other regional blocs and the world average. These are shown in Figures 1–6. The figures show that in terms of FDI net inflows, sub-Saharan Africa (SSA) has the highest net inflow from 2007 to 2017. Though the share of SSA's FDI may be small compared with the inflow of the world, there has been about a 2.5% increase between the period 2000 and 2007 (Ideue, 2018). In SSA inflow of FDI has been argued to be highly concentrated in South Africa and Nigeria in the period 2000–2007 since in the same period, both countries on average received about 32.5% of the SSA FDI inflows. According to Ideue (2018), inflows of FDI in SSA seem to be influenced by macroeconomic fundamentals and commodity prices, hence there is always a decline when these variables move in a negative direction. The net inflow declined below other regions (South Asia, European Union, Middle East, and North Africa) from 2017 to 2020. For the annual percentage of GDP growth, South Asia registered the highest growth rate followed by SSA while Europe is below the world average.

However, for access to electricity, sub-Saharan Africa (SSA) is far below the global average. Europe found itself at the top with its entire people having access to electricity followed by the Middle East and North Africa bloc. Such

TABLE 1 Variables and description.

Variables	Description	Source
GDP growth	The yearly percentage growth rate of Gross Domestic Product (GDP) at market prices is based on constant local currency.	World Bank's World Development Indicators (WDI)
GDP per unit of energy use (GDPP.E.U)	Measures the Purchasing Power Parity (PPP) GDP per kilogram of oil equivalent of energy use.	World Bank's World Development Indicators (WDI)
Energy use	Energy use per Purchasing Power Parity (PPP) GDP is the kilogram of oil equivalent of energy use per constant PPP GDP.	World Bank's World Development Indicators (WDI)
Access to electricity (Elect Access)	Measures the proportion of the population with electricity access.	World Bank's World Development Indicators (WDI)
Foreign Direct Investment (FDI)	Measures the net inflows (new investment inflows minus disinvestment) in the reporting economy from foreign investors and is divided by GDP	World Bank's World Development Indicators (WDI)
CO ₂ intensity	Kilogram per kilogram of oil equivalent energy use	World Bank's World Development Indicators (WDI)
CO ₂ emissions from residential buildings (CO ₂ emi R.B)	Captures all emissions from fuel combustion in households	World Bank's World Development Indicators (WDI)
CO ₂ emissions from manufacturing industries (CO ₂ emi M.I)	Captures the emissions from the combustion of fuels in industry	World Bank's World Development Indicators (WDI)
CO ₂ emissions from solid fuel (CO ₂ emi S.F)	Captures mainly emissions from the use of coal as an energy source. Measured as a percentage of the total	World Bank's World Development Indicators (WDI)
CO ₂ emissions from liquid fuel (CO ₂ emi L.F)	Captures mainly emissions from the use of petroleum-derived fuels as an energy source. Measured as a percentage of the total	World Bank's World Development Indicators (WDI)
Region	This was created by the authors and it measures the sub-regional status of the countries. Thus, West Africa = 1, East Africa = 2, Southern Africa = 3, and Central Africa = 4.	Self-created

Source: Authors' construct.

a high percentage of electricity access indicates that those economies are developed. This is because, as an economy grows, it calls for industrialization that is supported by increased energy consumption and increased production and consumption of household durables (electronics) that are electricity-dependent. This would lead to increased household electricity consumption. Halicioglu (2008) emphasized that economic growth and output could be jointly determined because higher levels of economic development necessitate larger levels of energy consumption.

On sustainable development, emissions of CO₂ from consumption of solid fuel (as a percentage of total emissions) show that sub-Saharan Africa (SSA) and South Asia are the top emitters (which are above global average emissions). This means that in both regions solid fuel consumption is high and intend contributes much to the total emissions. This feature of high solid fuel consumption shows how unsustainable the nature of fuel consumption in those regions is. Karakara et al. (2021) indicated that biomass fuel is the highest consumed fuel by households in SSA. Thus, such biomass consumption affects the environment leading to unsustainable development.

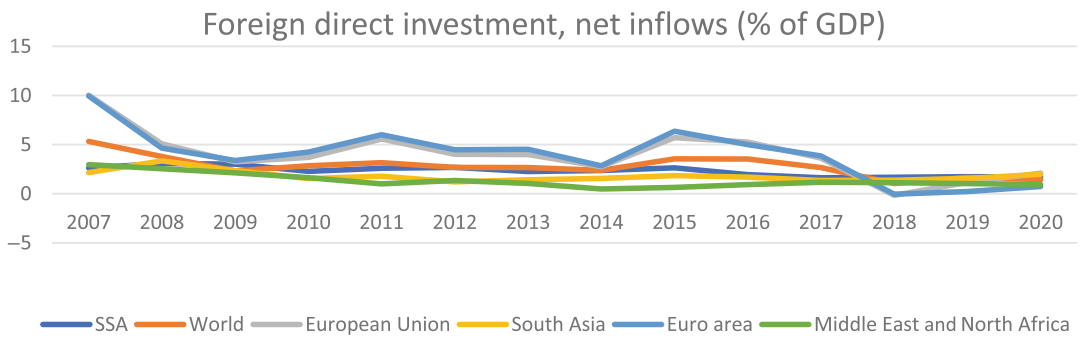


FIGURE 1 Foreign direct investment, net inflows (% of Gross Domestic Product). *Source:* Authors' computations.

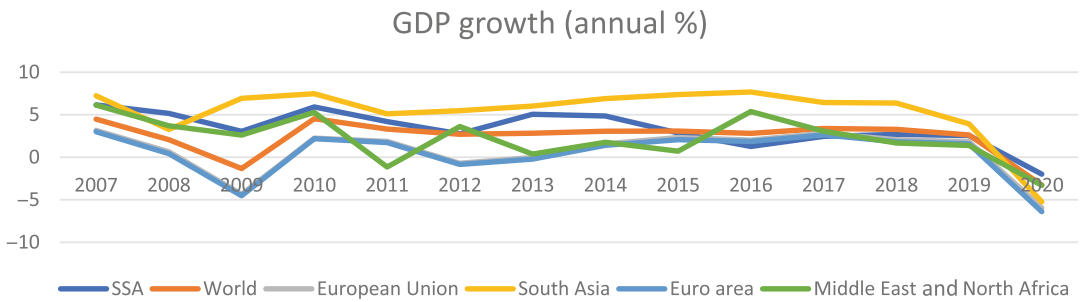


FIGURE 2 Gross Domestic Product growth (annual %). *Source:* Authors' computations.

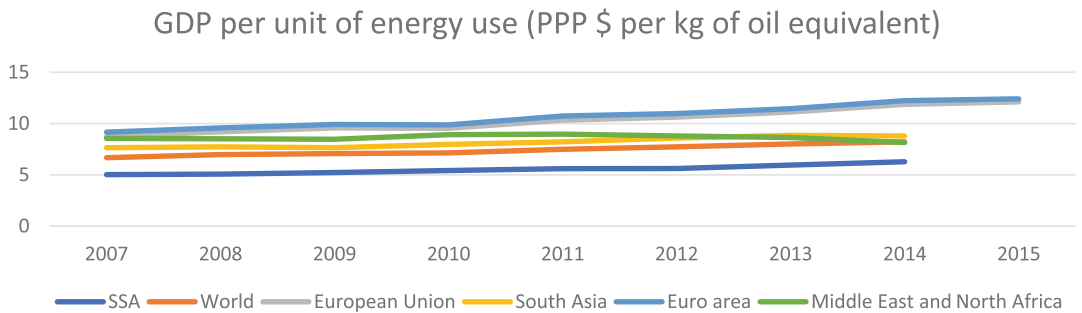


FIGURE 3 Gross Domestic Product per unit of energy use (Purchasing Power Parity (PPP) \$ per kg of oil equivalent). *Source:* Authors' computations.

Also, emissions of CO₂ emissions in construction and manufacturing industries as a percentage of total fuel combustion showed that South Asia has the highest percentage which is higher than the global average and SSA lingers below the global average. For GDP per energy use, the figure shows that sub-Saharan Africa (SSA) has the lowest GDP per energy use while other regions are above the global average. This shows that SSA uses less energy in its production. This means that economic activities that go on in sub-Saharan Africa (SSA) nations are linked to the consumption of fewer amounts of environmentally unfavorable sources of energy causing the emissions rate in the countries to rise. However, for household energy consumption, environmentally unfriendly (dirty) energies are consumed. This clearly shows the difference in sectorial energy consumption contributions to CO₂ emissions (sustainable development).

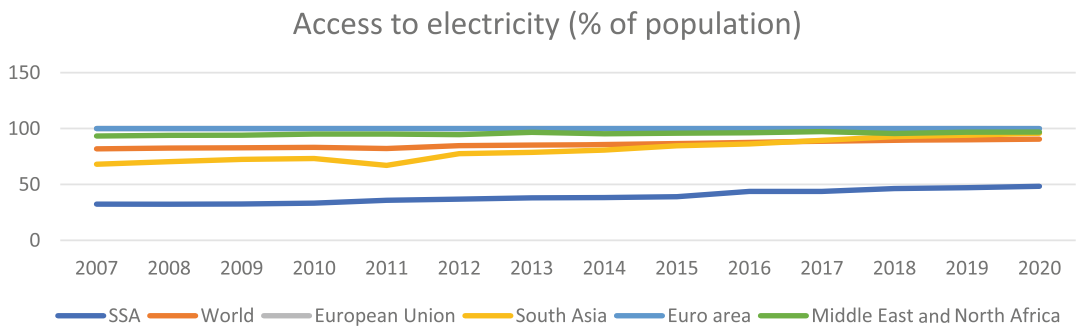


FIGURE 4 Access to electricity (% of the total population). Source: Authors' computations.

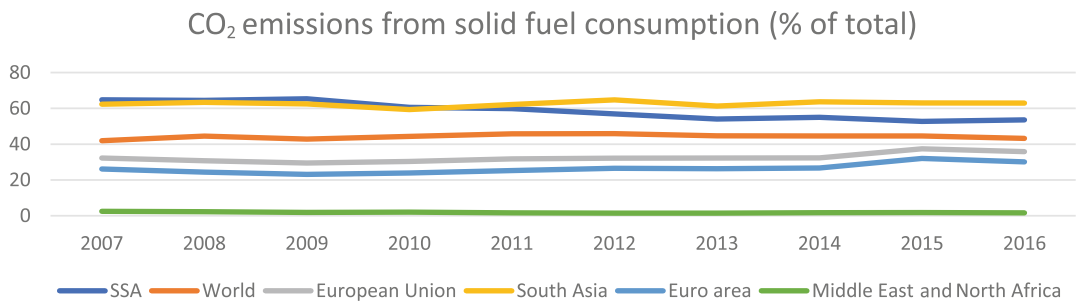


FIGURE 5 CO₂ emissions from solid fuel consumption (% of total sub-Saharan Africa (SSA)). Source: Authors' computations.

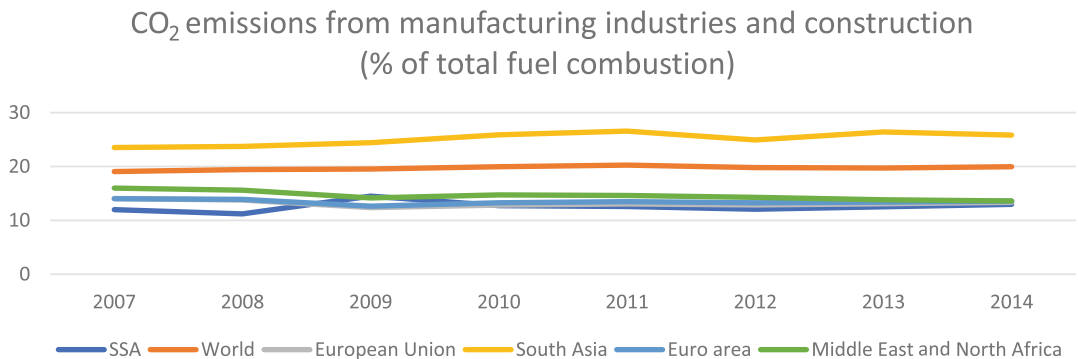


FIGURE 6 CO₂ emissions from manufacturing industries and construction (% of total fuel combustion sub-Saharan Africa (SSA)). Source: Authors' computations.

The trend of access to electricity is presented in Figure 4. South Asia and the SSA regions have a trend below the world average. However, after the year 2014, there was a steady rise in the trend of South Asia making it slightly higher than the world average. The Euro area has the highest figures for the period. Importantly, access to electricity in SSA as observed in Figure 4 is relatively low for the period 2007–2020 though a slightly upward trend is observed after the year 2015. The International Energy Agency reports that access to electricity or energy in SSA is the lowest compared with other regions in the world. About only 50% of the population in SSA have access to electricity, thus, approximately 600 million of the population lack electricity access while 890 million of the population lack traditional

fuels (IEA, 2018). World Bank (2018) also reports that access to electricity in 13 of the SSA countries is below 25% as compared to only one country in developing Asia.

The trend of CO₂ emissions from the consumption of solid fuel varies among the regions or areas under consideration. As presented in Figure 5, only the Euro area and sub-Saharan Africa (SSA) recorded trends beyond the world average for the period. The position for sub-Saharan Africa (SSA) is not shocking as about 40% of the population living below US\$1.9 daily as of 2018 according to the World Bank (2020), hence a majority of the households have no option but to make use of solid fuel for cooking (Oluwatosin et al., 2022). Thus, in sub-Saharan Africa (SSA), the basic source of energy meant for cooking in rural areas and some few households in most of the cities are from solid fuels like charcoal, firewood, agricultural residues, animal dung, and household wastes. Before the year 2010, the trend in CO₂ emissions from consumption of solid fuel in sub-Saharan Africa (SSA) was slightly beyond the trend in South Asia. However, there was a fall in the trend for sub-Saharan Africa (SSA) and a rise in the trend for South Asia after the year 2011. South Asia, the European Union, North Africa, and the Middle East all have trends below the world average for the period. Specifically, among the regions or areas under consideration, the Middle East and North Africa recorded the lowest trend. Again, a slight decrease in the trend for the Middle East and North Africa is observed after the year 2010.

Again, we present the trend analysis of CO₂ emissions originating from manufacturing and construction industries in Figure 6. It is observed that among the areas or regions considered, only South Asia recorded a trend above the world average for the areas. Increased modernization, per capita income, and FDI in the South Asia region are found to be the main drivers of high CO₂ emissions from manufacturing and construction industries (Amin et al., 2022). The European Union, sub-Saharan Africa (SSA), Euro area, and the Middle East and North Africa all recorded trends below the world average. For the regions or areas below the world average, it is observed that sub-Saharan Africa (SSA) had the least trend between the years 2007 and 2008. The trend, however, increased after the year 2008 surpassing the European Union but below the Middle East and North Africa.

3.2 | Methodological analysis

From the arguments of the Neoclassical and the energy economists, we conclude that energy is key for production and growth (Barro, 1988; Camarero et al., 2015; D. I. Stern, 1997). Also, the theoretical basis of the analysis follows the feedback hypothesis which on one side maintains that energy consumption drives economic growth. Thus, the study aligns itself with the theoretical positions of the Neoclassical, energy economists, and the feedback hypothesis hence modeling the consumption of energy as a driver of economic growth. This relationship is modeled including sustainable development as a driver of growth in Equation (1) as:

$$\text{GDP Growth} = f(\text{Energy Consumption Types, Sustainable Development}). \quad (1)$$

In this study, the measures for energy consumption types include energy access and access to electricity. Also, variables such as CO₂ intensity, CO₂ emissions from residential buildings, CO₂ emissions from manufacturing industries, emissions of CO₂ from solid fuel, and emissions of CO₂ from liquid fuel are used in measuring sustainable development. FDI and region are used as control variables. Thus, the region is introduced to capture the possible effect of the differences in the sub-regional status of the countries under study. Incorporating the measures of energy consumption types, sustainable development, and the control variables, we obtain Equation (2):

$$\begin{aligned} \text{GDP Growth}_{it} = & \varphi_0 + \varphi_1 \text{Energy Use}_{it} + \varphi_2 \text{Elect Access}_{it} + \varphi_3 \text{FDI}_{it} + \varphi_4 \text{CO}_2 \text{ Intensity}_{it} + \varphi_5 \text{CO}_2 \text{ emi R.} \\ & \text{B}_{it} + \varphi_6 \text{CO}_2 \text{ emi M.I}_{it} + \varphi_7 \text{CO}_2 \text{ emi S.F}_{it} + \varphi_8 \text{CO}_2 \text{ emi L.} \\ & \text{F}_{it} + \varphi_9 \text{Region}_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

denotes φ_0 represents the constant, $\varphi_1, \varphi_2, \dots, \varphi_9$ denote the parameters to be estimated while ε_{it} is the error term. Again, the subscripts $i (= 1, \dots, n)$ denote the country, and $t (1, \dots, T)$ denote the time (years) indices. The General

Methods of Moments (GMM) estimation technique is employed for the regression analysis. Thus, with the cross-sectional units ($N = 46$) being above the period of study ($T = 13$), the GMM is the appropriate technique. Also, this technique is used because it is capable of correcting endogeneity issues using the instrument (Blundell & Bond, 1998). From Equation (2), we specify the GMM model in Equation (3) also known as model 1 as:

$$\begin{aligned} \text{GDP Growth}_{it} = & \varphi_0 + \varphi_1 \text{GDP Growth}_{it-1} + \varphi_2 \text{Energy Use}_{it} + \varphi_3 \text{Elect Access}_{it} + \varphi_4 \text{FDI}_{it} + \\ & \varphi_5 \text{CO}_2 \text{ Intensity}_{it} + \varphi_6 \text{CO}_2 \text{ emi R.} \\ & \text{B}_{it} + \varphi_7 \text{CO}_2 \text{ emi M.I}_{it} + \varphi_8 \text{CO}_2 \text{ emi S.F}_{it} + \varphi_9 \text{CO}_2 \text{ emi L.} \\ & \text{F}_{it} + \varphi_{10} \text{Region}_{it} + \varepsilon_{it}, \end{aligned} \quad (3)$$

where subscript denotes growth in the previous year. It is important to note that in the current study, economic growth is measured using two different indicators: GDP growth (as specified in Equations (2) and (3)) and GDP per unit of energy use. Thus, using a latter variable as the dependent variable, the GMM model is specified in Equation (4) also known as model 2 as:

$$\begin{aligned} \text{GDPP.E.U}_{it} = & \varphi_0 + \varphi_1 \text{GDPP.E.} \\ & \text{U}_{it-1} + \varphi_2 \text{Energy Use}_{it} + \varphi_3 \text{Elect Access}_{it} + \varphi_4 \text{FDI}_{it} + \varphi_5 \text{CO}_2 \text{ Intensity}_{it} + \varphi_6 \text{CO}_2 \text{ emi R.} \\ & \text{B}_{it} + \varphi_7 \text{CO}_2 \text{ emi M.I}_{it} + \varphi_8 \text{CO}_2 \text{ emi S.F}_{it} + \varphi_9 \text{CO}_2 \text{ emi L.} \\ & \text{F}_{it} + \varphi_{10} \text{Region}_{it} + \varepsilon_{it}, \end{aligned} \quad (4)$$

where subscript denotes the previous year's GDP per unit of energy use. Thus, the regression results are presented with GDP growth as the dependent variable (Model 1) and GDP per unit of energy use as the dependent variable (Model 2).

4 | RESULTS AND DISCUSSIONS

4.1 | Descriptive statistics

Appendix C presents the descriptive statistics of the variables. We detect differences in the observations for the variables. This is an indication that there were missing observations for some variables, for some years in some countries. Consequently, an unbalanced panel dataset was used for the GMM analysis. An inspection of the maximum and minimum values for GDP growth and GDP per unit of energy use shows disparities among the countries used in the said indicators. The same can be said for CO₂ emissions from solid fuel. However, for CO₂ emissions from residential buildings, CO₂ emissions from manufacturing industries CO₂ emissions from liquid fuel, access to electricity and energy use, there are no disparities. This is also evident in the mean values being above the standard deviations as shown in Appendix C. The absence of outliers in CO₂ emissions from liquid fuel, manufacturing industries, and residential buildings can lead to the conclusion that most have similar characteristics in the emission of CO₂ from the identified sources. The statistics show that CO₂ intensity varies among the countries considered for the study. Thus, there is a large difference between the minimum and the maximum values. It is also evident from the fact that the standard deviation of CO₂ intensity is higher than the mean. Indeed, the minimum values and the presence of outliers of this variable confirm Zang et al.'s (2018) assertion that several SSA countries record CO₂ intensity below the world average and also vary significantly among the individual countries.

4.2 | Econometric results

In Appendix A, it is evident that there is an absence of multicollinearity in the variables employed. Thus, the VIF test presents values that are all below 10. Results from the models estimated are presented in Table 2 with Models 1 and

2 presented in columns 2 and 3, respectively. In both models, there is evidence of autocorrelation in the Arellano-Bond tests for the first lag, but no autocorrelation is detected in the second lag. The sub-regional status of the countries used for the study does not affect growth in the countries.

Regarding traditional conventions of the error term and preserving the degree of freedom, we discover that one lag is suitable for the equations. As a result, we use the right-side variables' lag order of 1. We utilize the lag order of one for the other variables in the equation and the lag order of two for the dependent variable as the instrument. Thus, the findings as presented in Table 2 indicate that the models are affected by autocorrelation in differentiated residuals in the first order (AR(1)). This is, however, corrected in the second-order (AR(2)) since we fail to reject the null hypothesis of the second-order (AR(2)) in difference for the nonappearance of autocorrelation in the residuals. In both models, the probability values of the Sargan test show that the instruments employed in the GMM estimation are validly exogenous. It is thus confirmed that the instruments used in the models do not correlate with the error terms. From the Hansen test, we fail to reject the null hypothesis that the overidentified model is specified correctly. We, therefore, conclude that the specification of the model is correctly done. Again, in restricting or minimizing the proliferation of instruments, it is seen that the instruments employed are less than the number of countries or cross-sectional units.

In Model 1, the measures of energy consumption are all positive and statistically significant. A unit increase in energy use and access to electricity improves economic growth by about 0.006 and 0.141 units, respectively, and all

TABLE 2 General Methods of Moments regression results.

Dependent variables		
Model 1: GDP Growth (GDP Growth)		
Model 2: GDP Per Unit of Energy Use (GDPP.E.U)		
Independent variables (1)	Model 1 (2)	Model 2 (3)
GDP Growth(−1)	−0.148** (0.072)	
GDPP.E.U(−1)		0.369*** (0.059)
Energy Use	0.006** (0.003)	−0.001*** (0.000)
Elect Access	0.141* (0.081)	0.034*** (0.008)
FDI	0.008 (0.092)	0.028** (0.012)
CO ₂ Intensity	4.572*** (1.544)	1.346*** (0.232)
CO ₂ emi R. B.	0.026 (0.108)	0.034 (0.023)
CO ₂ emi M. I	0.005 (0.089)	−0.003 (0.013)
CO ₂ emi S. F.	−0.002*** (0.000)	−0.003*** (0.000)
CO ₂ emi L.F	−0.018 (0.036)	−0.011** (0.005)
Region	−0.481 (0.036)	0.051 (0.253)
Constant	−3.850 (6.336)	2.294** (0.961)
No. of cross-sectional units	46	46
No. of instruments	37	38
No. of observations	156	152
AR(1)	0.001	0.000
AR(2)	0.434	0.889
Sargan OIR	0.210	0.311
Hansen OIR	0.689	0.724

Abbreviations: FDI, Foreign Direct Investment, GDP, Gross Domestic Product; OIR, overidentifying restrictions, *** , ** , * indicate statistical significance at 1%, 5%, 10% levels, respectively.

other variables held constant. The level of significance for energy use and electricity access is 5% and 10%, respectively. Thus, energy consumption and growth are positively related. This finding has earlier been reported by Ghosh (2002) in his studies. Ucan et al. (2014) also confirms a unilateral causation between energy use and economic growth while Abid and Seabri (2012) found no significant association when the relationship was studied using the Tunisian economy. It is thus reported that a positive association is obtained in the long and short term. Nevertheless, the degree of responsiveness to economic growth is high in the long term compared with the short term. This to a large extent is attributed to the growing technology and invention of new electrical appliances that continue to make work or any form of production easier. The finding is obvious and can be attributed to energy being an important component in the growth process as established in both theoretical literature (D. I. Stern, 1997) and empirical studies (Azam et al., 2015; Kazar & Kazar, 2014).

In the same model 1, we found that CO₂ intensity is statistically significant at 1% in affecting economic growth. The coefficient indicates that holding all other variables constant, a unit increase in CO₂ intensity leads to about 5.5-unit increase in economic growth. This finding means that as an economy grows, production increases, exploitation might increase, and this would increase CO₂ emissions. This is in line with what Nkengfack and Kaffo (2019) and Kahouli (2018) found. Erdogan et al. (2020) postulate that countries experiencing higher development use more energy, hence causing more environmental degradation (CO₂ emissions) than less developed countries. This conclusion is confirmed by the trend analysis performed in this study. Thus, SSA which is a relatively less developed region (compared with the European and South Asia) records lower trends in the CO₂ emission variables and is mostly below the world average. Also, Li et al. (2021) argue that energy consumption and urbanization increase CO₂ emissions, making way for the growth of the economies of the G20 nations. Similarly, a long-term association between urbanization, economic growth, and CO₂ emissions is confirmed in the MINT countries in a study by Odugbesan and Ryoub (2020). On the contrary, our findings indicate that CO₂ emission from solid fuel significantly reduces growth. Thus, economic growth is reduced by about 0.002 units in response to a unit increase in CO₂ emissions from solid fuel. Vujović et al. (2018) explain that CO₂ emissions from solid fuel influenced economic growth highly as compared to other forms of emissions such as those from liquid fuel. This is attributed to the fact that solid fuel sources are presently the most common sources of energy hence exerting the highest effect on the growth.

In Model 2, access to electricity has a positive effect while energy use hurts economic growth. Both variables are statistically significant at 1%. Thus, GDP per unit of energy use reduces by about 0.001 units when energy use increases by 1 unit, and all other variables are held constant. Again, a unit increase in access to electricity increases GDP per unit of energy use by about 0.034 units. Also, GDP per unit of energy use is enhanced by FDI. Thus, FDI is positively and statistically significant at 5% in impacting economic growth and GDP per energy use. This is in line with the earlier studies (Hasanov et al., 2017) and consistent with economic growth theories. Indeed, the positive correlation between energy use and economic growth is also confirmed by Özkocua and Özdemir (2017) when they found that there is a connection between environmental deterioration, consumption of energy, and growth in 26 OECD nations from 1980 to 2010. This was similarly acknowledged by Cetin and Ecevit (2018) that the energy-led-growth and trade-led-growth hypotheses are demonstrated for Turkey, China, Colombia, Jamaica, and Peru.

Consumption of energy increases as FDI improves, and in turn, there is a promotion of FDI inflow when energy consumption increases. Indirectly, growth in the economy is promoted through the improvement of energy consumption (Zeng et al., 2020). Thus, we found FDI to be the main determinant of growth in the countries selected, confirming the concept of the production function. Raheem and Yusuf (2015) established that capital in the form of FDI enhances the economic growth of countries in Africa. This is also confirmed by Kulu et al. (2021) who concluded from a study using a dataset on the Ghanaian economy that foreign investment makes good use of energy in the domestic economy that advances economic growth.

Also, at a 1% level of significance, CO₂ intensity is positive. GDP per unit of energy use is enhanced by about 1.346 units with a unit increase in CO₂ intensity. On CO₂ emissions, emissions from solid fuel were found to be negative while emissions from liquid fuel were positive. Respectively, emission from solid fuel is statistically significant at 1% while emission from liquid fuel is significant at 5%. This finding is partly because SSA countries consume more solid fuels and such fuels affect the environment through the emissions they create. This environmental damage

from solid fuels affects economic growth negatively, and liquid fuels have the reverse effect on economic growth. Usman et al. (2020) made similar conclusions that a causal association was built between ecological footprint and growth in the economy as well as bio-capacity in their studied countries.

Considering the sectorial differentials on the impacts, it is found that household or residential emissions have the greatest impact. Both models confirmed that CO₂ emissions from solid fuel (originating from households) are detrimental to GDP growth and GDP per unit of energy use. This is reasoned from the point that in SSA, households comparatively have a larger size and undertake a large number of activities. In SSA, CO₂ is emitted from solid fuels such as charcoal, firewood, agricultural residues, and wastes in households. Thus, household emission of CO₂ from solid fuel is on the rise in SSA (Adeeyo et al., 2022; Aemro et al., 2021). The transportation sector also matters in sustainability regarding the emission of CO₂ from liquid fuel in SSA. As evident in the findings from Model 2, this is significant concerning GDP per unit of energy use. Our findings lead to the conclusion that the household and transportation sectors significantly reduce growth in SSA through the emission of CO₂.

4.3 | Causality tests

In complementing the econometric findings from the GMM results, we further employ the Granger causality tests. This is also done to test the possible by-causality among the key variables being investigated. As presented in Table 3, four different hypotheses were tested. In null hypothesis 1, we test the causality between energy use and GDP growth in SSA. The probability values (in the case of Null Hypothesis 1) indicate a rejection of the null hypothesis that energy use does not Granger cause GDP growth. This confirms the findings from the GMM estimation. Thus, the Granger causality test shows that as more energy is used, there is a corresponding increase in growth in GDP in SSA. The hypothesis of growth which assets a connection from energy to growth is confirmed in this regard while the hypothesis of conservation and the feedback hypothesis are rejected in the case of SSA.

For access to electricity and GDP growth, we only reject the null hypothesis that GDP growth does not Granger cause electricity access according to the probability values. This implies that in SSA, growth in GDP makes way for the expansion of electricity access. Thus, an improvement in GDP equips the authority in terms of funds to acquire the necessary materials to expand access to electricity in the economy. It is important to state that the Granger causality tests confirmed no causality between energy use and GDP per energy use as well as electricity access and GDP per energy use.

TABLE 3 Pairwise granger causality tests.

Null hypothesis 1	Observations	F-statistics	Prob
Energy Use does not Granger cause GDP Growth	133	7.5967	.0012
GDP Growth does not Granger cause Energy Use		2.2146	.1134
Null hypothesis 2	Observations	F-statistics	Prob
Energy Use does not Granger cause GDPP.E.U	130	0.4119	.6633
GDPP.E.U does not Granger cause Energy Use		0.6808	.5081
Null hypothesis 3	Observations	F-statistics	Prob
Elect Access does not Granger cause GDP Growth	536	0.0144	.9857
GDP Growth does not Granger cause Elect Access		5.7685	.0033
Null hypothesis 4	Observations	F-statistics	Prob
Elect Access does not Granger cause GDPP.E.U	130	2.2211	.1128
GDPP.E.U does not Granger cause Elect Access		0.1777	.8374

Source: Authors' construct.
Abbreviation: GDP, Gross Domestic Product.

5 | CONCLUSIONS AND RECOMMENDATION

This study explores the sectorial differentials in energy consumption and how that affects the energy-growth nexus. Again, the study relates that to sustainable development. The study employed secondary data for 46 SSA countries for the period 2007–2020. Using the GMM estimation technique, we found that all the measures of energy consumption positively affect economic growth. Specifically, a rise in energy use and access to electricity improves economic growth. For our sustainable development variables, CO₂ intensity is positively related to growth while CO₂ emissions from solid fuels have a negative effect on economic growth. Again, FDI is positively and statistically significant at 5% in impacting economic growth and GDP per energy use. Thus, we found Foreign Direct Investments to be the key determinant of growth, which conforms with the concept of the production function.

The findings of this study point to the need to create subsidy policies that would encourage the consumption of clean and liquid fuels, and consumers to acquire appliances having high standards of energy efficiency to lower solid fuel consumption. The countries under study should also pursue conservation policies that are intended to lower energy intensity levels, with the adoption of new technologies that consumption of lessen energy in the home and industry, vary the current energy matrix to a more sustainable one, and develop new energy (possibly renewable energy) policies to support both economic development and environmental sustainability. This means that the countries concerned should formulate policies that will guarantee the reduction in CO₂ emissions to attain a quality environment. Also, the countries should carve out appropriate policies to attract and utilize FDIs in the countries to help promote economic growth.

The main limitation of the study is that while there are about 55 countries in SSA, the study made use of 46 countries owing to data availability. For future studies, it is recommended that studies concentrate on a country case study and expand the variables to include more variables relating to environmental destruction. Again, studies could look at the role of institutions in mediating these variables studied, preferably on regional strand or country case studies.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design of the study. Data collection and analysis and discussions were performed by Evans Kulu, Isaac Dasmani, and Mark Kojo Armah. The search for suitable literature and the first draft of the of the conception was written by Alhassan Abdul-Wakeel Karakara, and all authors contributed to its buildup. All authors read and approved the final manuscript.

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DATA AVAILABILITY STATEMENT

Data will be made available upon request from the corresponding author.

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APPENDIX A

VARIANCE INFLATION FACTOR (VIF)

	Variance Inflation Factor (VIF)	1/VIF
Energy Use	5.233	0.191
Elect Access	3.601	0.278
CO ₂ Intensity	2.702	0.37
CO ₂ emi S.F	2.504	0.399
CO ₂ emi L.F	1.895	0.528
Region	1.593	0.628
CO ₂ emi M.I	1.391	0.719
FDI	1.27	0.787
CO ₂ emi R.B	1.256	0.796
Mean VIF	2.383	

APPENDIX B

COUNTRIES USED FOR THE STUDY

Angola	Congo, DR.	Gambia, The	Madagascar	Rwanda	Togo
Benin	Congo, Rep	Ghana	Liberia	Senegal	Eswatini
Botswana	Cote d'Ivoire	Guinea-Bissau	Lesotho	Seychelles	Eritrea
Burundi	Djibouti	Guinea	Mozambique	South Africa	Zimbabwe
Burkina Faso	Comoros	Kenya	Niger	Sierra Leone	Zambia
Cameroon	Ethiopia	Malawi	Nigeria	Sao Tome and Principe	Cabo Verde
CAR	Gabon	Mali	Namibia	Tanzania	
Chad	Equatorial Guinea	Mauritania	Mauritius	Uganda	

APPENDIX C

DESCRIPTIVE STATISTICS

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP Growth	628	3.826	4.719	−36.392	20.716
GDP P.E.U	183	9.69	16.895	2.076	224.714
Energy Use	192	704.032	682.154	9.563	3129.067
Elect Access	644	42.769	25.58	1.279	100
FDI	635	5.208	9.024	−11.199	103.337
CO ₂ Intensity	192	1.861	7.415	0.093	103.158
CO ₂ emi R.B	184	8.233	6.726	0	31.084
CO ₂ emi M.I	184	14.869	10.877	1.639	55.147
CO ₂ emi S.F	460	9116.337	58,693.414	0	418,639.39
CO ₂ emi L.F	460	74.517	24.449	7.391	123.628
Region	644	2.130435	1.076429	1	4

Abbreviations: Obs, Observation; Std. Dev, standard deviation.