Environmental Sustainability Evaluation in Sub-Saharan Africa: Energy Consumption and Environmental Degradation

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Abstract
Economic development requires intensive energy consumption, which has caused severe environmental degradation. Moreover, achieving environmental sustainability is still challenging in developing countries where the environment is experiencing a significant degradation trend. The research aims to evaluate the environmental sustainability and the energy consumption patterns in Sub-Saharan Africa. In doing so, the spatially varying relationship between energy consumption and environmental degradation were considered. The Exploratory Spatial Data Analysis (ESDA) was applied. This research also stands apart from prior ones by incorporating the interdisciplinary theoretical approach the Environmental Kuznets Curve (ECK). The result displays the energy consumption pattern for 2000 and 2022. The findings can contribute to appropriate policies recommendations for energy consumption in African regions.

Keywords: Environmental Sustainability, Energy Consumption, Environmental Degradation

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Introduction

Energy consumption in Sub-Saharan Africa is heavily reliant on biomass and fossil fuels (Lahnaoui et al., 2024). As energy demand rises, there is a heightened risk of environmental degradation due to the over reliance on unsustainable energy sources like trees and precious minerals (Kagzi et al., 2024). Li and Lin (2015) demonstrated that rapid urbanization and industrialization also contribute to a rise in energy consumption in the region. Moreover, other studies found that it is challenging for Sub-Saharan African countries to provide reliable and sustainable energy to their populations (Agoundedemba et al., 2023). Individuals' lack of access to electricity led to their reliance on biomass as an alternate energy source for domestic activities like cooking. Consequently, the escalation of anthropogenic activities such as deforestation and mining present a significant environmental risk owing to energy extraction (Sonter et al., 2020). Furthermore, urbanization leads to the expansion of informal settlements, which increases energy needs, and pressures on natural environment (Yu et al., 2024). Consequently, cities tend to be ill-equipped to manage energy use from the environment, contributing to biodiversity loss and environmental degradation (Voumik & Sultana, 2022).

Numerous studies have attempted to address the challenges environmental degradation generated from economic activities. The environmental Kuznets curve theoretical approach stipulates that the early phases of economic development are linked to a rise in environmental degradation (Grossman & Krueger, 1991). This is due to the constant use and exploitation of natural resources and industrialization. So as African nations are trying to rise there are environmental consequences. The Environmental Kuznets Curve (EKC) has been the subject of considerable discussion, particularly regarding developing nations such as Sub-Saharan Africa, where economic growth, energy consumption, and environmental challenges converge.

Past studies have been done on climate change impacts on the environment in Sub-Saharan Africa. Some of these studies highlighted the energy consumption and its impact on the environment. Shi and Umair (2024) focused on the balance between industrialization, agriculture, and ecosystem preservation. Islam and Winkel (2017) studied climate change impact on the environment and found that regional poverty, lack of access to resources, and gender inequalities cannot ensure sustainable benefits in all aspects of society, especially for the marginalized groups. Clement and Isbi (2019) focused on sustainable development projects in the region and found that insufficient evaluation of the successes and challenges of such projects negatively impacted policy and sustainability. Besides, some research shed light on the role of indigenous knowledge and innovative solutions to environmental challenges (Boiral et al., 2020). Additionally, studies attributed the sustainable, well-being, and long-term ecological balance to environmental and socio-economic factors (Hariram et al., 2023). Farrukh and colleagues (2023) highlighted that a lack of effective management of water, land, and forest resources results in overuse and degradation. These findings appear to be convincing to some extent regarding environmental sustainability. However, they are insufficient to explain the reasons for the environmental sustainability challenges and energy consumption trends in Sub-Saharan Africa. Moreso, there are several studies that evaluate environmental sustainability in Sub-Saharan Africa without the role of space. However, they did not sufficiently tackle the regional environmental sustainability and energy consumption patterns in Sub-Saharan Africa. It is against this backdrop that this paper attempts to analyze the environmental sustainability and energy consumption patterns in the Sub-Saharan Africa region. Moreover, there is a lack of studies with the role of space (physical location). This research also evaluates the spatial distribution of energy consumption. The spatial data analysis is a successful tool to give an effective policy recommendation especially at regional level.

Methodology

Study Area

The forty-eight (48) Sub-Saharan African countries are the study's geographic coverage. The United Nations Population Division (2024) estimates that there are roughly 1,259,902.35 billion people living in Sub-Saharan African nations. Sub-Saharan Africa continues to exhibit the lowest per capita energy consumption (Deichmann et al., 2011). The region's expected economic growth, the population and accelerating urbanization process are closely linked to the rising demand for energy consumption.

Sub-Saharan Africa is classified into four distinct economic and political categories, each of which implements an environmental program. The Economic Community of West African States (ECOWAS) comprises fifteen countries located in West Africa. The Southern African Development Community (SADC) includes fifteen nations located in the southern part of the continent. The Intergovernmental Authority on Development (IGAD) consists of eight-member states from the Horn of Africa, the Nile Valley, and the African Great Lakes region. Lastly, the Economic Community of Central African States (ECCAS) is made up of eleven countries in Central Africa.

Despite Sub-Saharan Africa being a less contributor to environmental pollution in comparison to other continents such as Asia, the rising energy consumption can contribute to environmental degradation. Besides, many nations do not have the necessary capacity to respond and adapt (Deichmann & Zhang, 2013). Some studies show that energy consumption in Sub-Saharan Africa significantly relied on traditional biomass fuels such as wood, charcoal, and dung for household requirements (Smith et al., 2015). Biomass fuels are frequently the preferred energy source in rural areas since they can typically be obtained locally without incurring additional costs (Karekezi & Kithyoma, 2002). However, these energy sources cause environmental issues and health issues for the people who use them, especially women and children (Biran et al., 2004; Bryceson & Howe, 1993). The 10 nations facing the greatest risk from climate change effects are from Sub-Saharan Africa, specifically Sierra Leone, South Sudan, Nigeria, Chad, Ethiopia, Central African Republic, and Eritrea (Sarkodie, 2018).

Data Collection

In this study, the data was collected from the International Energy Agency (IEA, 2024). The Energy Consumption data in Sub-Saharan Africa was collected from 1980 to 2022 and the Energy Total Final Consumption by Source was collected from 1990 to 2022 as shown in figures 1 and 4.

Research Variable. This research uses exploratory spatial data analysis methods to analyze the spatial distribution of energy consumption and the environmental degradation issues. The research used Geoda and QGIS software packages to analyze the distribution of energy consumption in Sub-Saharan Africa.

Based on the literature review, the current study uses two variables: energy consumption and the Energy Total Final Consumption by Source. The variable helps to understand the energy consumption pattern in Sub-Saharan Africa as shown in Figure 1. Then, the study compared the distribution of energy consumption for the year 2000 and 2022. The shapefile was then taken from QGIS.

Data Analysis

Exploratory Spatial Data Analysis (ESDA). Exploratory Spatial Data Analysis (ESDA) helps to identify the pattern of data and summarize the main characteristics of the data. The conventional method of Exploratory Data Analysis (ESDA) helps to understand the spatial relationship between the variables and their evolution over time.

Local Spatial Autocorrelation (LISA). Anselin and colleagues (2007) state that global spatial autocorrelation is utilized to determine overall clustering and spatial correlation, but it does not provide a graphical representation of clusters or outliers.

Spatial Distribution Map. The ESDA was used at two stages in time: 2000 as an initial year and 2022 as the final year to draw the spatial distribution maps. The geographical distribution maps aid in understanding the spatial pattern and distribution of energy consumption in Sub-Saharan African nations. They provided a general overview of the regional variation of energy consumption in Sub-Saharan African countries. Lighter color indicates a low amount of energy consumption, while the darker color signifies a high value of energy consumption.

The empirical findings are organized into two sections. The first portion discusses the geographical analysis of 48 Sub-Saharan African countries at the national level, while the second section presents the national level LISA analysis to identify high-high and low-low clusters within nations.

Results

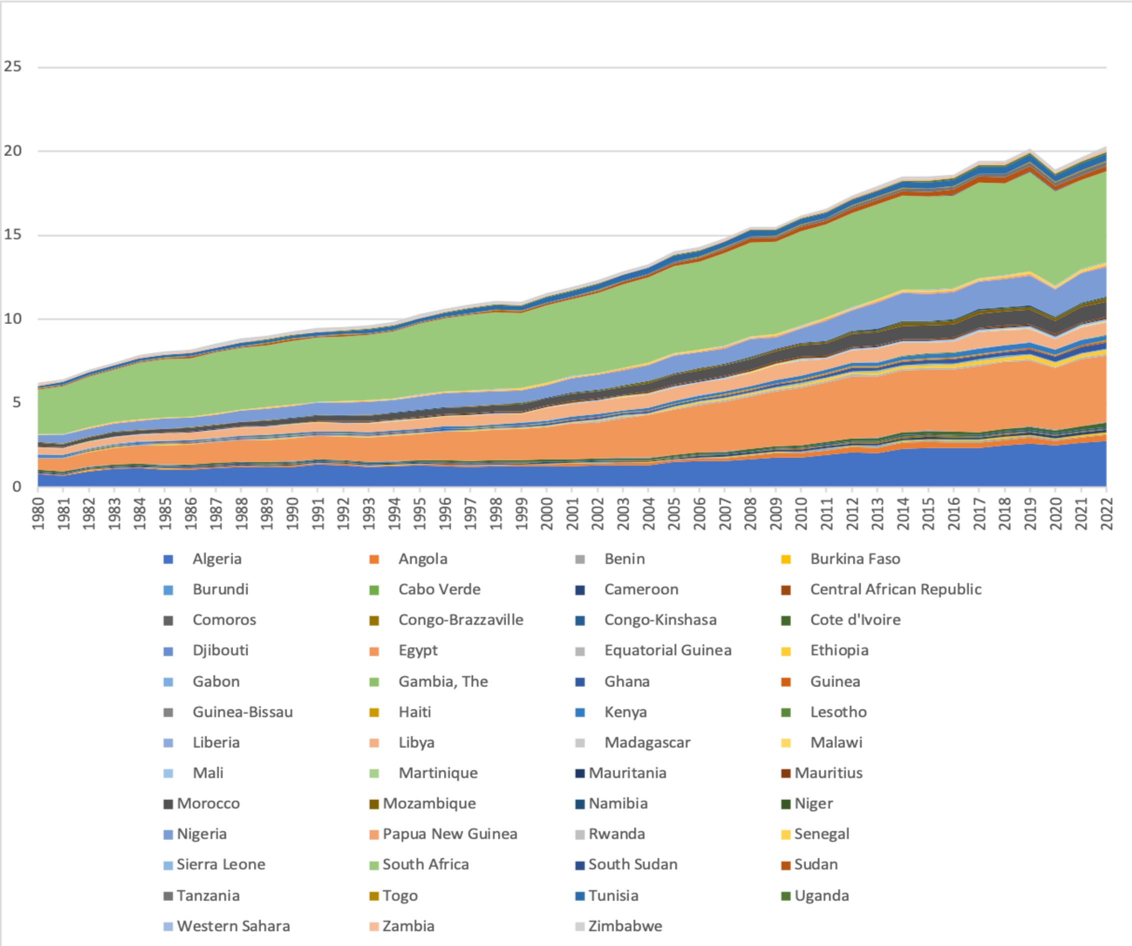
Energy Consumption in Sub-Saharan Africa

South Africa uses the most energy, followed by Egypt in second place and Algeria. Nigeria is ranked fourth. South Africa is the most industrialized country in the continent. The country displays the highest energy consumption. Although the nation’s energy mix is varied, coal accounts for a sizable amount of it, which raises per capita consumption. Recent events suggest that growing electricity costs and environmental concerns are driving a move toward liquefied petroleum gas. Nigeria has the largest population in Africa, yet its per capita energy consumption is still quite low. This is ascribed to economic concerns, infrastructure issues, and the fact that many places have limited access to dependable energy.

Democratic Republic of the Congo (DRC) has one of the lowest per capita energy consumption rates in the region, despite having substantial hydroelectric potential. Challenges such as political instability and inadequate infrastructure have hindered energy development.

Sub-Saharan Africa's energy consumption is among the lowest globally. Efforts to enhance energy access are ongoing, with initiatives focusing on renewable energy sources and infrastructure development. However, disparities persist, and many countries continue to face challenges in meeting the energy needs of their populations.

Figure 1: Energy Consumption in Sub-Saharan Africa



Source: International Energy Agency, 2024

Mapping Energy Consumption in Sub-Saharan Africa Countries

This result outlines the overall energy consumption landscape across Sub-Saharan African nations (Figure 2). It involves an analysis and quantification of the spatial distribution of energy use within the region. The regional distribution of energy consumption in Sub-Saharan Africa, generated reveals major discrepancies throughout the continent. The map helps to examines and visualizes the relationship between energy use and a variety of socioeconomic and geographical characteristics. The analysis of the distribution pattern is shown in Figure 2.

The map (Figure 2) shows that Southern African countries, particularly South Africa, have the highest energy usage. The darker tones on the map imply higher energy consumption. South Africa's industry, which mainly relies on coal-powered electricity generation, is a significant contributor to the country's high energy consumption. Urban centers in Western Africa, such as Nigeria urbanized areas, have greater energy consumption rates. Despite infrastructure issues, Nigeria's energy demand has increased due to population density and urbanization. These locations are marked with intermediate shades on the map.

Moderate Consumption Zones. East Africa for instance, Kenya and Ethiopia consumption patterns vary throughout the region. While Kenya consumes moderate amounts of energy, Ethiopia's consumption is comparatively modest, despite producing significant amounts of hydroelectric electricity. Many rural communities continue to have limited access to power, resulting in lower consumption.

Low Consumption Areas. Democratic Republic of Congo has some of the lowest energy consumption levels, as shown by the colors that are lighter on the map. Despite the potential for hydroelectric electricity in the Democratic Republic of Congo, political turmoil and a lack of infrastructure limit universal energy availability. Some countries frequently struggle with inadequate energy infrastructure, resulting in considerable regional disparities in energy usage. For instance, In the rural Areas the low consumption rates are due to a lack of grid access and reliance on traditional biomass fuels.

The geographical landscape significantly affects energy consumption patterns in Sub-Saharan Africa, where coastal and urban regions typically have a better energy access compared to inland and rural locales. The availability of energy resources, such as the hydroelectric potential found in the Congo Basin and the extensive coal reserves in South Africa, further influences this access.

According to Szabó and colleagues (2021), approximately 56% of the Sub-Saharan African population lacks access to modern energy sources. In contrast to East and South Asia, where the figures stand at 3% and 11%, respectively (Szabó et al., 2021). Figure 2 illustration shows that energy consumption in some African countries has experienced minimal changes. Some countries remain static. Sub-Saharan Africa is recognized as the region with the most significant energy access shortfall worldwide. Projections suggest that household energy consumption will rise as more families gain access to energy and as appliance ownership increases (Dagnachew et al., 2020).

The causal relationships between energy consumption and economic growth exhibit significant variation across different nations (Odhiambo, 2010). This finding is also consistent with the outcomes of this study. The most developed African nations exhibit a higher energy consumption. The recent energy consumption patterns in Sub-Saharan Africa as shown in Figure 2 reveal several critical challenges, highlighting a considerable dependence on traditional biomass fuels, such as wood, charcoal, and dung, to meet household energy needs.

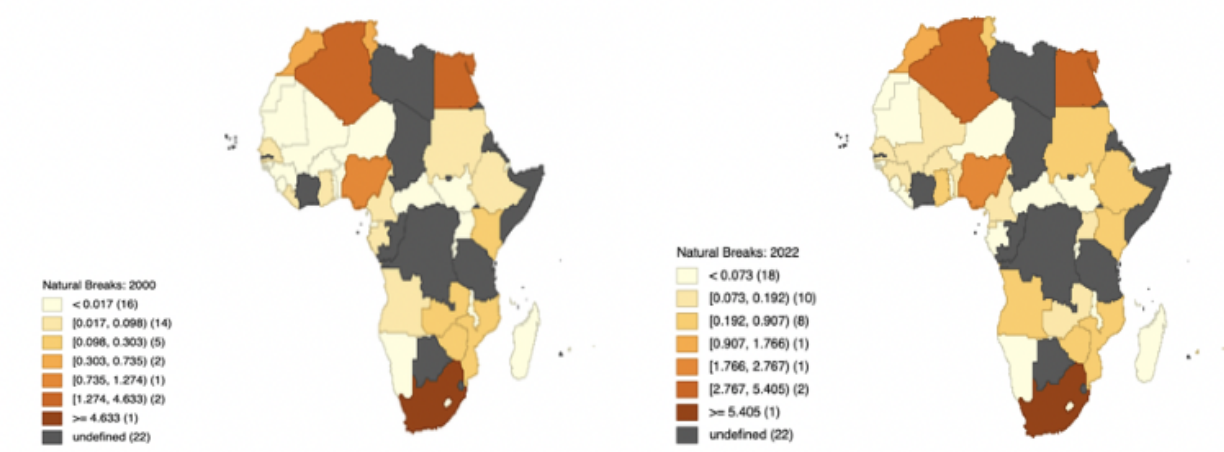
A nuanced understanding of the geographical disparities in energy consumption can help in formulating regional policies within the same economic group of Sub-Saharan African countries. In Mali, energy consumption has seen an upward trend. Similarly, Ethiopia has experienced increased energy consumption during the same period, with hydropower serving as a vital energy source. Ethiopia is home to the Grand Ethiopian Renaissance Dam (GERD), one of Africa’s largest hydroelectric projects. Nonetheless, the reliance on hydropower poses challenges due to the region's susceptibility to climate variability and droughts, which can adversely affect water flow to hydroelectric facilities.

In Mozambique and Zambia, energy consumption has also risen (Figure 2). Despite the promise of these energy sources, several obstacles persist, including inadequate infrastructure, high capital expenditures for renewable energy initiatives, and disparities in energy access. Many Sub-Saharan African nations are now prioritizing a transition to more sustainable energy systems, motivated by both domestic requirements and global climate change obligations.

South Africa leads in energy consumption, followed by Egypt and Algeria. The principal findings indicate that economic activity significantly influences both supply and demand growth. However, this growth is constrained by outdated infrastructure, leading to inefficiencies and increased conversion losses (Shabalov et al., 2021).

Figure 2: Spatial Distribution of Energy Consumption in Sub-Saharan Africa Countries

a) Distribution of Energy Consumption in 2000   b) Distribution of Energy Consumption in 2022



Note: QGIS 3.42 was used to generate the map
Source: Author

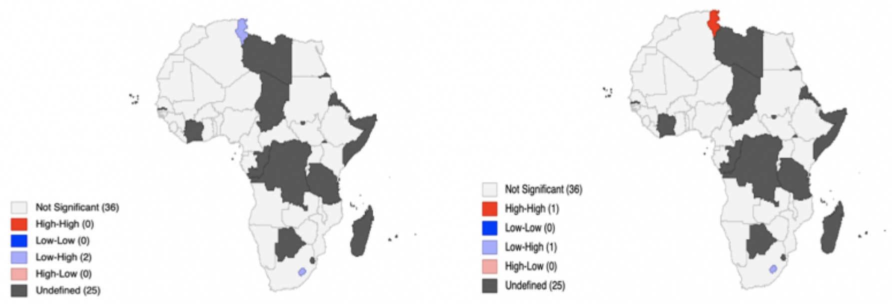
Local Spatial Autocorrelation (LISA)

The result indicates the high-high and low-low clusters for the years 2000 and 2022 (Figure 3).

The LISA map results are categorized into four groups: one is clusters of high-valued countries surrounded by high-value neighbors and low-valued countries surrounded by low-value neighbors. The other two are outliers: high-value regions surrounded by low-value neighbors, or low-value regions surrounded by high valued neighbors. The overall spatial patterns of clusters in both maps (initial year and final year) are similar, which means there is spatial persistence. For the year initial year 2000, the LISA map display two low-high and the final year shows one high-high.

Figure 3: LISA Map

a) LISA Cluster Map in 2000 b) LISA Cluster Map in 2022



Note: QGIS 3.42 was used to generate the map and Geoda was used to generate LISA
Source: Author

Environmental Degradation and Energy Source Africa

High levels of indoor air pollution from burning biomass for cooking and heating are damaging to human health (Prasad, 2011). Biomass including firewood and charcoal, continues to be a prevalent energy source in numerous regions of Africa alongside fossil fuels. Although classified as a renewable resource, its excessive utilization has led to considerable environmental challenges. The widespread deforestation and land degradation resulting from the extensive harvesting of trees for firewood and charcoal production are particularly concerning. In nations such as Ethiopia, Uganda, and Kenya, this reliance has resulted in diminished biodiversity, decreased soil water retention, and heightened desertification. Additionally, traditional biomass combustion methods contribute to air pollution, posing health hazards to local communities (Bishop et al., 2019).

Energy resources in Africa, especially fossil fuels like coal, oil, and natural gas, play a major role in environmental damage. The burning of these fuels emits carbon dioxide (CO_2) and other greenhouse gases into the air, speeding up climate change. African nations rich in fossil fuel resources, such as Nigeria and South Africa, depend on these energy sources for economic growth, yet their extraction and utilization cause significant environmental harm. This is in alignment with the initial stage of Environmental Kuznets Curve. In South Africa, coal extraction significantly contributes to deforestation, soil degradation, and air contamination. The combustion of coal to generate electricity emits significant amounts of CO_2, a major contributor to global warming (Oberschelp et al., 2019).

The dependence on hydropower as a sustainable energy source in certain African nations also entails environmental repercussions. Although hydropower is classified as renewable, the establishment of large dams can significantly disrupt local ecosystems and biodiversity. The creation of dams and reservoirs often results in the inundation of extensive areas, displacing both human populations and wildlife. Furthermore, the modification of natural water cycles can disturb aquatic ecosystems and may contribute to the decline of fish species, which are essential for the livelihoods of numerous African local communities. The Inga Dam initiative in the Democratic Republic of Congo exemplifies the delicate balance between the demand for energy and the potential ecological damage involved (Schreiner et al., 2021).

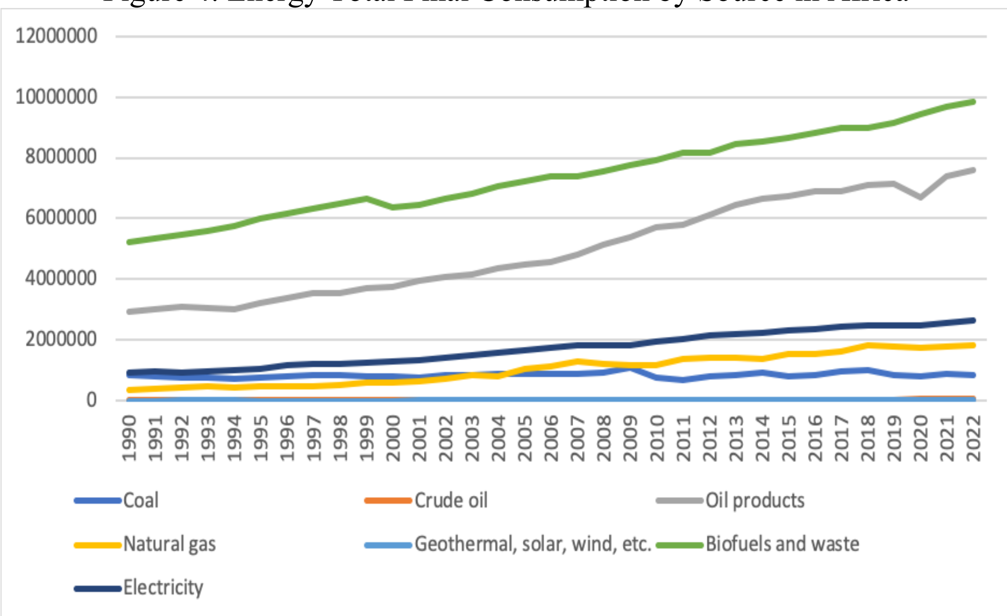
Although solar and wind energy are often promoted as environmentally friendly alternatives, they are not without their own ecological issues. The manufacturing of solar panels and wind turbines necessitates the extraction of various metals, including cobalt, lithium, and rare earth elements, which can adversely impact local ecosystems. In regions such as the Democratic Republic of Congo, where a substantial amount of cobalt is sourced, mining activities have led to environmental degradation characterized by soil erosion, deforestation, and water contamination. While these renewable energy sources play a crucial role in diminishing dependence on fossil fuels, the associated mining operations present considerable environmental challenges (Goodman, 2020).

The graph illustrates the total final energy consumption by source in Africa. Various energy sources are utilized in Sub-Saharan Africa, some of which have detrimental effects on the environment and contribute to ecological degradation.

Africa possesses over 40% of the world's reserves of cobalt, manganese, and platinum, which are essential minerals for battery and hydrogen technologies. Currently, South Africa, the Democratic Republic of the Congo, and Mozambique play a significant role in global production of these minerals (IEA, 2024).

In Sub-Saharan Africa, 74.9% of electricity generation is derived from the combustion of natural gas, coal, and oil. Biofuels and waste accounted for 39% of energy sources, while oil contributed 26% (IEA, 2024). Furthermore, approximately 80% of the population in sub-Saharan Africa relies on solid fuels such as wood, charcoal, and coal for cooking (Prasad, 2011).

Figure 4: Energy Total Final Consumption by Source in Africa



Source: International Energy Agency, 2024

Countries like South Africa, which has a relatively high per capita income in comparison to other Sub-Saharan nations, have witnessed both significant energy consumption and notable environmental degradation, such as air pollution from coal-fired power plants (Kohnert, 2024). Conversely, many other nations in the region, such as Ethiopia and Rwanda, show progress in environmental sustainability, relying on renewable energy sources and low-carbon development strategies.

In the context of Sub-Saharan Africa, the Environmental Kuznets Curve (EKC) hypothesis has shown mixed results. While some countries have experienced economic growth alongside improvements in environmental quality, many still face significant challenges. The relationship between energy consumption, and environmental degradation may not follow the standard EKC curve due to factors such as low levels of industrialization, dependence on natural resources, and weak environmental policies.

Conclusion and Recommendations

This study aimed to do exploratory geographical data analysis to examine the distribution of energy consumption across countries. The findings reveal that in some African nations there were no significant change in energy consumption over the years due to the traditional source of energy. Few countries are experiencing a higher energy consumption over time due to their industrialization. The findings give policy-relevant insights and conclusions for geopolitical and economic decisions. This can also contribute to policy recommendations, particularly in Sub-Saharan Africa, where there is little to no data. The policy advice can contribute to drawing regional environmental protection policies, increasing technology and research, and should also be highlighted by government policy. A solution to attain environmental sustainability is achievable, but it requires the commitment of the government, strong institutions, private sector, and international organizations.

Mapping energy consumption serves as a valuable resource and base for policymakers, African economic community and development communities to pinpoint areas with the most pressing energy deficiencies. A strong emphasis on project initiatives can be done to enhance energy access in economically disadvantaged communities through off-grid solutions, including solar energy systems and rural electrification initiatives.

In the context of Sub-Saharan Africa, the Environmental Kuznets Curve (EKC) hypothesis highlights the necessity of implementing sustainable development strategies that balance economic advancement with environmental stewardship. Essential policy initiatives should include the promotion of renewable energy alternatives, such as solar, wind, and hydroelectric power, which can help alleviate the ecological consequences associated with energy consumption. Additionally, it is crucial to enhance environmental regulations, boost energy efficiency, and invest in green technologies to mitigate the negative impacts of economic growth on the environment.

A significant area of policy emphasis should be on enhancing access to modern energy services for all communities, especially in rural regions, to diminish dependence on traditional biomass and foster the adoption of cleaner energy options. Moreover, fostering international collaboration, along with providing financial and technical assistance for sustainable energy infrastructure, is imperative to address regional environmental challenges.

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