

A Data-Driven Assessment of Solar and Wind Energy Potential and Renewable Pathways In Africa

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Abstract

As the world confronts the realities of climate change, the transition from fossil fuels to renewable energy has become both an environmental necessity and an economic opportunity. Africa, endowed with abundant sunlight and promising wind corridors, remains heavily reliant on fossil fuels and hydropower, leaving much of its renewable potential untapped. This study provides a data-driven assessment of solar and wind prospects across the continent, examining their role in fostering economic growth. Using panel data from 2010 to 2022, the analysis explores the relationship between renewable energy adoption and GDP performance in African countries, while drawing comparisons with nations such as Denmark, Germany, and China that have successfully expanded their renewable capacity. The findings suggest that scaling up solar and wind in Africa could cut reliance on fossil fuel imports, improve energy security, and stimulate long-term economic development. However, progress depends on more than resources alone: political stability, sound policies, and infrastructure investment are essential. The study concludes that Africa's renewable transition requires strategies tailored to regional conditions, positioning solar and wind as key drivers of both sustainability and growth.

Keywords: Renewable Energy; Solar and Wind Power; African Continent; Economic Growth; Renewable Energy Development; Panel Data Analysis

1. Introduction

The twenty-first century has placed energy and climate at the center of global development, economic growth, and stability (Askari & Parsa, 2024). For Africa, blessed with resources yet constrained by weak infrastructure and poverty, this challenge is both urgent and an opportunity. Solar and wind energy stand out as renewables that could accelerate growth, cut emissions, and reposition the continent in the global clean energy transition. Climate impacts—droughts in the Sahel and floods in East Africa—already disrupt millions (Meierrieks, 2021). The Paris Agreement’s 1.5°C target underscores Africa’s chance to leapfrog fossil fuels and adopt renewables as foundations of growth.

The sharp decline in renewable costs strengthens this case. Solar panels, once too costly, are now affordable, while wind technologies have become cheaper and more efficient (Creutzig et al., 2017). Yet demand across Africa rises rapidly with population and urban growth (Sokona et al., 2012). Without intervention, reliance on fossil fuels would deepen emissions and insecurity. Despite contributing less than 4% of global emissions, Africa faces severe climate risks (Serdeczny et al., 2017). Renewables thus bring a dual benefit: cutting global emissions while boosting local economies through jobs, reliable power, and reduced fuel imports.

Debates often cite the Environmental Kuznets Curve (EKC), which suggests pollution falls after wealth and innovation rise (Stern, 2017). But Africa can bypass this trajectory through renewables. With some of the world’s richest solar potential and growing wind opportunities, countries like Morocco, Egypt, and Kenya have begun large-scale projects (Baul et al., 2018). Yet most of this capacity remains untapped, reflecting the need for stronger policies and investment.

Recent studies note how African nations are starting to incorporate artificial intelligence and machine learning technologies in planning and managing renewable energy (Adeyinka et al., 2023). The technologies enhance energy prediction, maximize grid distribution, and minimize maintenance expenditures—significant variables in bridging infrastructure deficits that long hampered penetration. The findings imply that the digitalization of the energy economy of Africa can spur the acceleration of renewable deployment while being consistent in efficiency and sustainability. Nonetheless, this development needs cooperative investment in the data infrastructure, human resource, and regional cooperation.

Concerns about intermittency—no sun at night, fluctuating winds—are being resolved through storage, hybrid systems, and smart grids. Advances in localized solar modeling across African cities, such as improved temperature-based estimations of solar radiation in regions like Ilorin, Nigeria (Y. B. Adediji et al., 2021), are helping optimize system design and forecast energy output more reliably. Combined, solar and wind can even outperform fossil fuels in resilience and cost over time. Africa now faces a crossroads: either repeat destructive fossil-based growth or build a sustainable path. If nations succeed, they will secure energy, growth, and climate leadership. This report examines Africa’s renewable potential, barriers to adoption, and the policies needed to unlock it—arguing that investment in solar and wind is both an environmental necessity and a driver of resilience.

2. State of Renewable Energy in Africa

2.1 Benefits of Wind and Solar Energy to Communities

Wind and solar energy are transforming the planet's energy consumption and are crucial for achieving clean energy systems (Arora et al., 2025). Wind energy converts the energy in blowing air into electricity with the help of turbines, and solar energy uses sunlight with specific panels or concentrated solar power systems (Hannan et al., 2023). These technologies are not merely engineering feats; rather, they also reflect a significant shift in the ways that people create and consume energy. To get a deeper understanding of them, it is crucial to be familiar with key concepts such as capacity factor, which considers the efficiency of energy generation relative to the peak potential, intermittency, which reveals that sunlight and wind are variable, grid integration, which ensures that renewable power integrates with existing power systems, and off-grid systems and energy storage technologies that ensure reliable power supply away from towns or in undeveloped regions (Adediji, 2022).

The benefits of solar and wind power extend far past generating electricity (Millstein et al., 2024). From an environmental viewpoint, solar and wind power realize significant greenhouse gas and air pollution avoidance, supporting climate change mitigation and achieving direct public health benefits through avoidance of air pollution-related respiratory and cardiovascular diseases. From production of solar panels and wind turbines through installation, maintenance, and R&D, solar and wind industries drive comprehensive economic opportunities and encourage technological progress (Oladimeji et al., 2023). By adopting wind and solar power, countries experience cost benefits alongside increasing energy security, since dependence on imported fossil fuels diminishes (Adebisi & Moloji, 2024).

Socially, these technologies are enabling access to electricity in communities that have historically been underserved (Mbelu et al., 2024). Off-grid solar systems and microgrids are illuminating rural villages, powering schools, clinics, and small businesses, and supporting economic and educational development. Beyond localized benefits, wind and solar energy support national and continental objectives for sustainable development, providing scalable solutions that can be integrated into broader energy planning and policy frameworks.

Technological improvements substantially increase the efficiencies of solar and wind power. Innovations in battery storage technologies enable energy captured at points of heightened production to be stored and used at points of reduced generation, thereby resolving the challenge of intermittency (Njema et al., 2024). Smart grid technologies optimize the entire system performance through careful balancing of supply against demand, utilizing mixed sources of energy, and enabling real-time control and management. Installation of hybrid systems, which combine solar, wind, and storage technologies, is gaining popularity in order to ensure a reliable and consistent supply of electricity in urban and rural environments.

Although issues of cost for initial investments, land use, intermittency, and requirements of supporting infrastructure and regulatory policies remain, these are countered by policy benefits, public and private cooperative partnerships, and global cooperation. With ongoing research and development improvements, wind and solar energy become not only alternate sources, but key

components of development of resilient, sustainable, and equitable energy infrastructure capable of achieving global climate objectives and delivering reliable, affordable power supplies for the world's communities.

2.2 Previous Studies and Efforts in combating Climate Change

Over time, scholars have devoted great effort to critically scrutinizing the interaction between growth, energy consumption, and environmental issues. One of the most influential ideas to come out of this debate in an early phase was the Environmental Kuznets Curve (EKC). This theory put forward that poor nations, in seeking to grow, tend to exploit natural resources wantonly and cause immense pollution. As these nations, though, reach increased affluence, technological knowhow, and good governance, they increasingly shift to more than ever sustainable practices, diverting investments to environmental conservation and economies (Wang et al., 2023). While debate still surrounds the EKC, it has triggered an important debate as to whether economic growth and environmental sustainability can coexist.

As climate science progressed, attention shifted from purely economic theories to the real-world impacts being felt on the ground. What once sounded like distant warnings in scientific reports has now become a lived reality. People in every region are experiencing record heatwaves, unpredictable rainfall, more frequent floods, longer droughts, and wildfires that devastate both lives and livelihoods (Lohmann & Kontoleon, 2023). Researchers no longer speak only in projections; they document how farmers lose entire planting seasons to delayed rains, how coastal communities battle rising seas, and how cities buckle under power outages during heatwaves (Carr et al., 2022)

Another theme that has emerged in the literature is the frequency and severity of extreme events. Studies consistently show that these events are no longer outliers but part of a new normal. Hurricanes and cyclones are stronger, rainfall patterns more erratic, and prolonged droughts more common. Scientists have begun to track how multiple extremes (drought followed immediately by flash floods) are hitting the same regions in short succession, leaving little time for recovery. This recognition has pushed researchers to think less about isolated “events” and more about a cascading pattern of risks that test the resilience of communities and economies.

Following these accumulating risks, technology development has branched out towards increasing energy efficiency and storage robustness. Recent findings, for example, the production of lead-free BaTiO₃-based dielectric ceramic capacitors, were seen as a potential path for sustainable yet high-performance energy storage technologies that enable renewable integration and climate resilience (Y. Adediji et al., 2023)

In parallel, social scientists have examined climate change's human dimensions. Research shows that environmental stress reaches beyond crop failures or dewatering of streams; it has an appreciable effect on mental health, population migration, and social stability (Hayes et al., 2018). Adolescents who live in areas at risk from climate change express an intense feeling of fear over their future prospects, for instance, while family members in at-risk areas often find themselves being pushed to migrate, leading to urban overcrowding and competition for limited resources (Meo et al., 2025). Such findings underscore the fact that climate change spills outside

scientists' and engineers' realms; it is radically transforming social systems, cultural systems, and political systems.

There has also been a growing recognition that the burden of climate change is unevenly distributed. Scholars point out that while wealthier nations historically contributed the most to greenhouse gas emissions, it is the poorer regions that suffer the harshest consequences (Levy et al., 2017). This global imbalance has become a major subject of research, not just in terms of environmental justice but also in terms of what kind of international frameworks and support systems are needed. Many studies highlight how vulnerable regions particularly Africa, face climate disasters with far fewer resources for adaptation and recovery.

Finally, research has been focusing more and more on solutions. Earlier research focused mostly on the costs of dealing with climate change, but more recent studies focus on the chances. Researchers have shown that renewable energy, which was once thought to be too expensive, is now competitive and even cheaper than fossil fuels in some cases (Batz Liñeiro & Müsgens, 2025). More and more research is being done on how decentralized solar systems can light up rural areas, how wind farms can make national grids more stable, and how geothermal energy can help us use less fuel from other countries. Insights from analogous fields, such as the creation of biodegradable magnesium-based alloys in biomedical engineering, underscore the significance of innovation that is both sustainable and contextually relevant (Y. Adediji & Adediji, 2024b). Many recent researches have changed their tone from warning to possibility. This shows that with the right investments and policies, the future can be both sustainable and more open to everyone.

2.3 Responses to Climate Change in Africa

Across Africa, governments and regional bodies are stepping up responses to climate change. The African Union provides frameworks for mitigation, adaptation, and sustainable development, which complement national energy and climate policies (Obah-Akpowoghaha et al., 2022). Countries such as Morocco, Egypt, South Africa, and Kenya have expanded solar, wind, and geothermal capacity, while others like Nigeria, Ghana, and Ethiopia are introducing clean energy policies and electrification programs (Zhang et al., 2023). Adaptation is also advancing. Cities are strengthening flood defenses and early warning systems, while farmers adopt climate-smart practices such as drought-resistant crops and improved irrigation. Social dimensions matter too: awareness campaigns, youth-led initiatives, and inclusive planning are helping communities adapt and engage (Hayes et al., 2018).

Regional collaboration is growing. Platforms such as the African Climate Policy Centre and ClimDev-Africa enable knowledge sharing, technology transfer, and access to climate finance. Innovations in smart grids, off-grid solar, and climate modeling are improving energy access and resilience (Shrestha et al., 2019). Still, challenges remain. Weak governance, poor infrastructure, financing gaps, and limited research capacity slow progress, while poverty and inequality limit large-scale investment (Ajia, 2025). Yet despite these barriers, Africa's trajectory shows increasing coordination, innovation, and ambition toward a more sustainable energy future.

2.4 Challenges in Africa's Energy Implementations

Africa is confronted with many challenges as it strives to upgrade its energy infrastructure and support it purely from renewables (Ajia, 2025). Since the continent enjoys abundant solar, wind, hydro, and geothermal resources, the pursuit of a sustainable energy future confronts the continent with huge challenges. The process of development is held back by weak governance, ineffective policy administration, and political turbulence. Further, socio-economic factors such as poverty and inequality pervasively hurt the investment potential in renewable energy facilities.

Moreover, outdated energy grids and inadequate infrastructure continue to be significant issues that further impede the successful integration of new renewable power plants with end-users. In addition, access to finance continues as a perpetuating malady for the same reasons many countries continue to rank as high-risk investment targets for deterring local and foreign investors. The process is also further muddled by gaps in technology, limited research, as well as foreign technology dependence. Environmental vulnerabilities, including extreme weather events and droughts, also result in undermined energy supply reliability.

Finally, the social dimension cannot be overlooked. Lack of awareness, limited education on renewable systems, and weak community engagement often lead to misuse or neglect of installed facilities. Altogether, these factors create a complex area that Africa must navigate if it is to achieve an equitable and sustainable energy transition.

2.4.1 National Governance and Institutional Factors

Africa possesses a wealth of natural resources, including plentiful sunshine, robust wind corridors, and extensive geothermal reserves (Elbarbary et al., 2022). These resources position the continent uniquely to spearhead the adoption of renewable energy; however, the realization of this potential is often compromised by inadequate governance and weak institutional capacity. Insufficient political leadership continues to pose a significant challenge, with long-term strategic vision often sacrificed for immediate political benefits. Frequently, public funds that could catalyze investment in renewable energy initiatives are either misallocated or diverted, hindering progress toward national and regional energy objectives. Furthermore, political instability and frequent changes in government diminish investor confidence, as policies may shift or be discarded before their full implementation. Corruption exacerbates these issues, creating conditions in which contracts are awarded based on favoritism rather than competence, thereby undermining efficiency and effectiveness.

A further aspect of the challenge revolves around the inconsistency inherent in energy policies themselves. As many governments espouse lofty renewable energy targets, the omission of overt implementation plans or the frequent unwinding of policies operates to discourage significant investment. Fossil fuel subsidies remain prevalent in many countries, which not only consolidate economies into carbon-intensive pathways but also send mixed signals both domestically to entrepreneurs as well as internationally to investors (Diallo et al., 2024). Incompetent institutions struggle with coordinating between many ministries, leading to fragmenting strategies whereby energy, environmental, and economic planning are not holistically integrated. The lack of accountability and transparency in government means that, even when projects commence, they often experience delays, go over budgetary limits, or eventually get shelved. Lacking strong,

transparent, and visionary leadership, Africa risks not taking advantage of a huge renewable energy potential for sustainable development.

2.4.2 Socio-Economic factors

Socio-economic realities represent one of the most pressing barriers to Africa's energy transition (Lawal, 2023). Poverty levels remain high across much of the continent, with millions of households unable to afford even the basic cost of electricity. For many, modern energy is a luxury rather than a necessity, and this deeply affects the demand needed to sustain large-scale renewable energy investments. High unemployment rates and limited disposable incomes mean that households and small businesses struggle to adopt decentralized clean energy technologies such as rooftop solar systems or mini-grids, even when these solutions are technically available.

The financial crises extend beyond domestic households and affect domestic economies. Many African governments face rising debt levels and constrained fiscal space, meaning little opportunity exists for substantial public investment in renewable facilities (Ashour & Sayed, 2024). In those cases when relief from donors or the private sector exists, such projects are small-scale, pilot-based, and difficult to sustain over the long term. The up-front costs of technologies like wind power, large power stations with solar panels, and batteries for storing energy are not affordable in situations when capital markets lack depth and domestic financing options remain limited. This creates a negative cycle: limited access to affordable finance inhibits the development of renewable power, and the lack of large schemes inhibits further economies of scale.

Inequality also shapes the energy landscape. Rural communities, which often have the greatest need for electricity, are the least likely to attract investment, as companies prioritize more profitable urban centers. The social consequences are profound: without reliable energy, schools cannot modernize, health facilities struggle to function, and economic opportunities remain limited, perpetuating cycles of poverty. Furthermore, affordability issues are not just about income but also about pricing structures. Subsidies for fossil fuels in many countries keep conventional energy artificially cheap, while renewable options are left comparatively more expensive, discouraging adoption.

Coupled, these socio-economic limitations would indicate that the energy transition of Africa not only constitutes a technological imperative but also a development necessity. In the absence of poverty reduction, a lessening of inequalities, and a restructuring of financial mechanisms for the facilitation of inclusivity, the clean energy revolution shall prove unthinkable for the millions of Africans for whom it would serve the greatest good (Kabutey-Ongor et al., 2025).

2.4.3 Infrastructure and Technical Barriers

Africa's renewable energy revolution is constrained by fragile infrastructure. Most national power grids are aging, maintained inadequately, and not suited for the mass integration of variability sources such as wind and solar energy (Agoundedemba et al., 2023; Bogunjoko, 2024). In the rural communities, whereby transmission lines may not exist or may not be reliable, even the successful renewable energy initiatives cannot afford reliable power supply. Storing

energy is a persistent bottleneck. Solar power occurs during the daytime and wind is unreliable depending on the weather, but bulk storage facilities like high-end batteries or pumped hydro continue to be too costly for the majority of the African governments (Bloomfield et al., 2022). As with other resource-intensive activities, such as the recycling of polyethylene terephthalate plastics entailing unique infrastructure and investment (Adediji & Adediji, 2024), renewable energy storage requires financial and technological investments which come up short.

Equally critical is the deficiency of technological expertise and logistic backup. The majority of states lack engineers, and a reliance on foreign contractors makes projects costly and slow to implement. Inadequate transport connections also slow the movement of heavy renewable equipment into the interior. Lacking modern grids, inexpensive storage, and strong human capital, Africa could undertake renewable energy facilities ambitious of vision but limited of scope.

2.4.4 Financial and Investment Factors

Financing is one of the biggest hurdles to Africa's renewable energy transition. While the likes of solar farms and wind parks are cheaper in the long term, they need huge initial investment (Pappis, 2022). Most African nations, however, experience high public debt and narrow fiscal space, and huge renewable mass commitments prove challenging. This has resulted in the government depending highly on foreign donors, development institutions, and private investors. Nevertheless, political instability, incomplete regulatory regimes, and sudden policy reversals deter foreign direct investment, and a few nations—such as South Africa, Morocco, and Kenya—manage big renewable funding (Dube & Horvey, 2023).

These domestic financing constraints underscore this. High interest rates and limited access to inexpensive credit deter local entrepreneurs from funding decentralized projects such as solar mini-grids or off-grid plants. Even when loans are offered, the cost of borrowing ends up becoming prohibitive, thus rendering small- and medium-scale renewable schemes economically unproductive. Simultaneously, investors also prefer quick exits, but renewable energy schemes need patient capital and broad risk-sharing structures. Furthermore, the unavailability of proper insurance products against currency volatilities, policy risk, and project timelines also diminishes the confidence of investors (Anekwe et al., 2024).

Lacking robust financial systems, Africa's renewable energy shift may turn out lop-sided, with a few states seeing gains as the rest fall behind due to their lack of investment-friendliness. Closing this gap demands creative solutions: creating indigenous capital markets, reducing access barriers for credit, and increasing public–private partnerships. Climate finance from abroad will continue to play a significant role, but creating sustainable, homegrown financial architectures is paramount for the renewable energy growth not only becoming a reality but also a reality for everyone at the continent level.

2.4.5 Social Acceptance and Community Engagement

In most African societies, renewable energy technologies such as solar farms, wind farms, and mini-grids continue to be unfamiliar and not well comprehended. That lack of awareness

frequently generates abandonment, misuse, or even vandalism—though not always from a spirit of malice, but from poverty, unfamiliarity with the technology, or the view that these systems are the outsiders' (Ikejemba & Schuur, 2018). Largely without the right education, the long-term advantages—reduced energy bills, cleaner air, and new economic opportunities—hardly get valued. Exclusion from planning exacerbates the problem. When communities are not consulted when projects are proposed, individuals feel excluded, which cements the view that these facilities are imposed upon them instead of belonging to them. Perception from cultures as well as inequalities, for instance, gender barriers to participation, also influence acceptance. In a few rurality settings, renewable technologies invite suspicion when the gains are not evident or not adequately clarified. Similarly a lack of institutional inclusion and public engagement often undermines the sustainability of development projects (El-Yaqub A. B et al., 2024)

However, stories of success also exist. Local population training, economic benefit sharing, and involving cooperatives—as the case of the solar mini-grids of East Africa shows—depict rising sustainability. Community engagement makes communities custodians rather than mere consumers. Social acceptance does not solely depend on information but also on respect, inclusivity, and mutual ownership without which the best technology does not work (Tseou-Nkokoane et al., 2023).

3. Methodology

3.1 Research Design

The study employs a qualitative secondary data analysis. The research employs public datasets from reputable international and local institutions. The datasets contain data for the renewable energy indicators including the use of fossil fuels, level of electrification, as well as the relevant socio-economic indicators for the African nations. The research methodology was preferred over the traditional data collection methodology whereby data is actually collected. The secondary dataset will also be supported by data from recent studies for the purposes of providing contextual insight.

Analysis of the data will cover comparative analysis (e.g., comparing disparate African regions or comparing Africa with international standards) as well as descriptive statistics (e.g., means, rates of growth, proportions). Graphical representation such as maps and charts will also be used for the effective representation of the pattern. Use of the quantitative evidence as well as the literature-based insight provides a holistic assessment of the opportunities and challenges for the renewable energy transition for Africa.

3.2 Data collection and Analysis

The datasets for this study were obtained from two reliable and widely used sources: the World Data Bank and the International Renewable Energy Agency (IRENA). The World Data Bank, managed by the World Bank Group, provides comprehensive access to economic, financial, social, and environmental datasets collected from countries worldwide. The dataset used in this

study covered 54 African countries as well as selected case-study countries outside Africa—Germany, China, the USA, and Spain—over a 26-year timeframe (1990–2015). Thirteen explanatory variables relevant to renewable energy and electricity production were extracted for analysis.

Complementing this, data from IRENA, founded in 2009 to support countries in accelerating their renewable energy transitions, was utilized to provide information on wind and solar energy generation and installed capacity. This dataset covered both Africa and Europe, spanning a 24-year period, and allowed for cross-continental comparisons of renewable energy deployment and infrastructure. These two datasets were chosen because they are authoritative, publicly accessible, and widely used in policy, research, and development planning.

The datasets underwent rigorous cleaning before analysis. Missing values, which were relatively small in proportion, were removed to avoid introducing distortions or biases. Duplicate records and inconsistencies were checked and eliminated to ensure data integrity. This process was necessary to ensure that the dataset was unbiased, consistent, and suitable for meaningful analysis. By addressing these data quality issues, the dataset was prepared for robust statistical and comparative evaluation.

Analysis was conducted using Python within the Jupyter Notebook environment, chosen for its versatility in handling large datasets and its extensive libraries for data cleaning, visualization, and statistical analysis. The primary methods employed were comparative analysis, visual exploration, and trend analysis. These methods were appropriate because the research objective was not only to assess Africa’s renewable energy performance but also to benchmark it against leading global actors and highlight patterns over time. Visualizations and descriptive statistics were particularly effective in revealing long-term trajectories rather than year-to-year fluctuations, which might be affected by short-term shocks.

The comparative approach focused on situating Countries in Africa’s renewable energy progress against both Europe and leading “Big 5” countries—namely the USA, Germany, China, Spain, and Denmark. These countries were selected as benchmarks because they are recognized global leaders in renewable energy adoption and innovation, providing useful standards for measuring Africa’s progress. Additionally, African countries were grouped into regional clusters (e.g., North, East, West, Central, and Southern Africa) to provide a clearer picture of intra-continental variations and to highlight regional strengths and weaknesses. For instance, this framework allowed for analysis of how Kenya’s geothermal and solar initiatives compared to Morocco’s large-scale solar projects or South Africa’s renewable auctions.

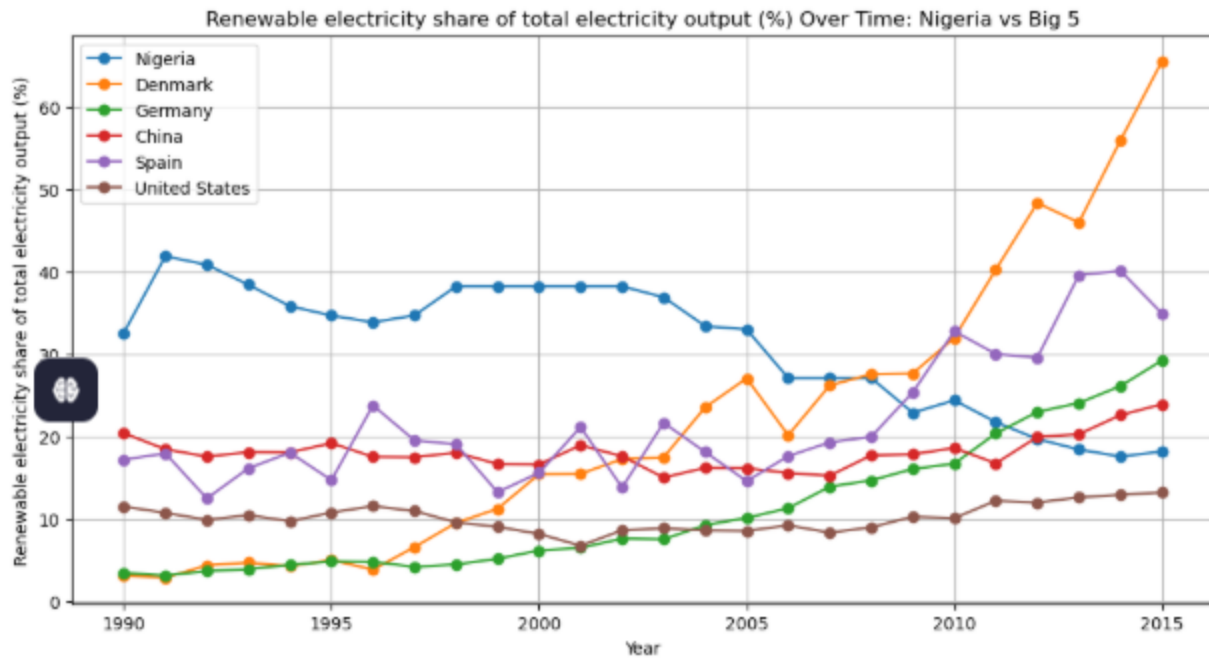


Figure 1 Comparative analysis of Nigeria’s Renewable share of total electricity output (%) with the big 5

To present the findings effectively, several visualization techniques were employed. Line plots were used to compare Africa’s solar and wind energy installed capacity and generation with Europe’s over time, making long-term trends and gaps easier to interpret. Bar charts and regional comparison plots were created to illustrate differences within Africa, while country-specific visuals compared African countries with the Big 5 in terms of renewable electricity share of total electricity output. These methods were chosen because they clearly highlight trends, disparities, and progressions across time and space, offering an intuitive way to communicate complex datasets.

Despite the robustness of the data, some limitations were encountered. Missing values and uneven reporting across African countries were challenges that limited the scope of certain variables. Additionally, while long timeframes were available for most indicators, a few datasets had shorter spans, reducing comparability in some cases. These limitations were mitigated by focusing on long-term patterns and averages rather than short-term fluctuations. Furthermore, while visualizations are effective for trend analysis, they do not capture all nuances of policy implementation or social acceptance, which require complementary qualitative insights. Nevertheless, the methods employed ensured reliable and meaningful comparisons across regions and countries.

4. Results and Discussions

4.1 Continental Comparisons

The comparison reveals an extraordinary disparity in Africa and European renewable energy evolution in wind and solar sectors. For wind electricity generation, Africa and European countries started at very close initial points in 2000. Nonetheless, while European wind generation grew extensively in each of the following years, Africa's never expanded and oscillated in the vicinity of zero compared to Europe's great rise in the full 24-year period like in Figure 1. There is a comparable trend in the installed capacity of wind energy. The two regions began from zero in 2000; however, an appreciable increase in installed capacity in Europe is an indication of significant investments and favorable policies. The installed capacity in Africa recorded negligible growth basing on the slow continental trend of developing infrastructure shown in Figure 2.

Africa and Europe too began at zero in or around 2000 in terms of Solar Energy Generation . But whereas Europe recorded a very sharp rise after 2005 to well over 280,000 GWh by 2025 in Africa, it remained below 25,000 GWh in Africa in spite of abundant solar resources (Figure 3). This is an indication of the difference between what is achievable and what is actualized on the African continent regarding exploiting solar energy. The same is the case with installed capacity in solar energy. European installations increased from close to zero in 2000 to over 330,000 MW in 2023. African capacity remained less than 25,000 MW in the same time frame and provides evidence of a vast shortage in infrastructure and policy (Figure 4).

$$\text{Capacity} = \frac{\text{Actual generation}}{\text{Installed capacity} \times \text{Time}}$$

$$\text{Wind Energy capacity for Africa} = \frac{15000 \times 10^9}{9000 \times 10^6 \times 8760} = 19.3\%$$

$$\text{Wind Energy capacity for Europe} = \frac{580000 \times 10^9}{260000 \times 10^6 \times 8760} = 25.5\%$$

$$\text{Solar Energy capacity for Africa} = \frac{25000 \times 10^9}{25000 \times 10^6 \times 8760} = 11.4\%$$

$$\text{Solar Energy capacity for Europe} = \frac{280000 \times 10^9}{330000 \times 10^6 \times 8760} = 9.7\%$$

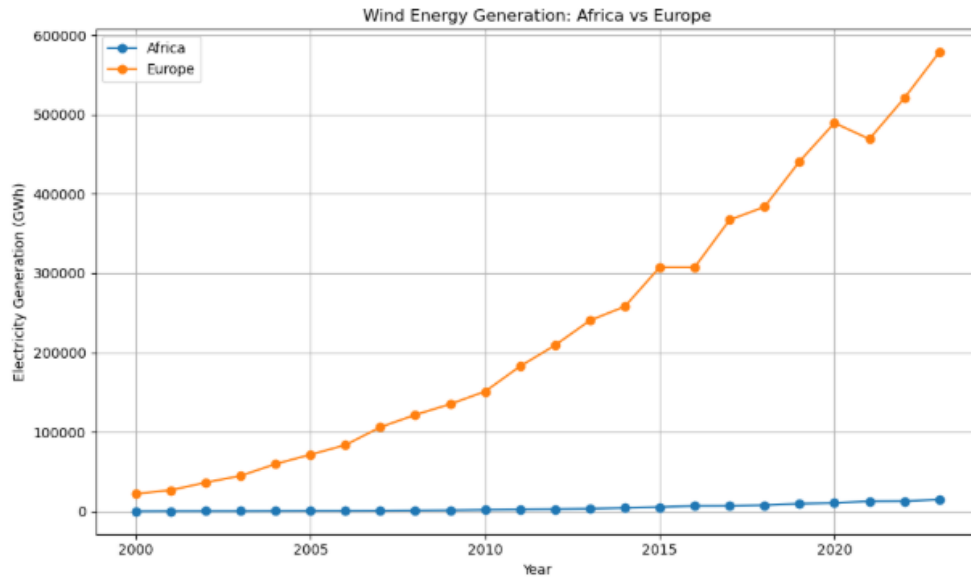


Figure 2 Wind Energy Generation of Africa against Europe

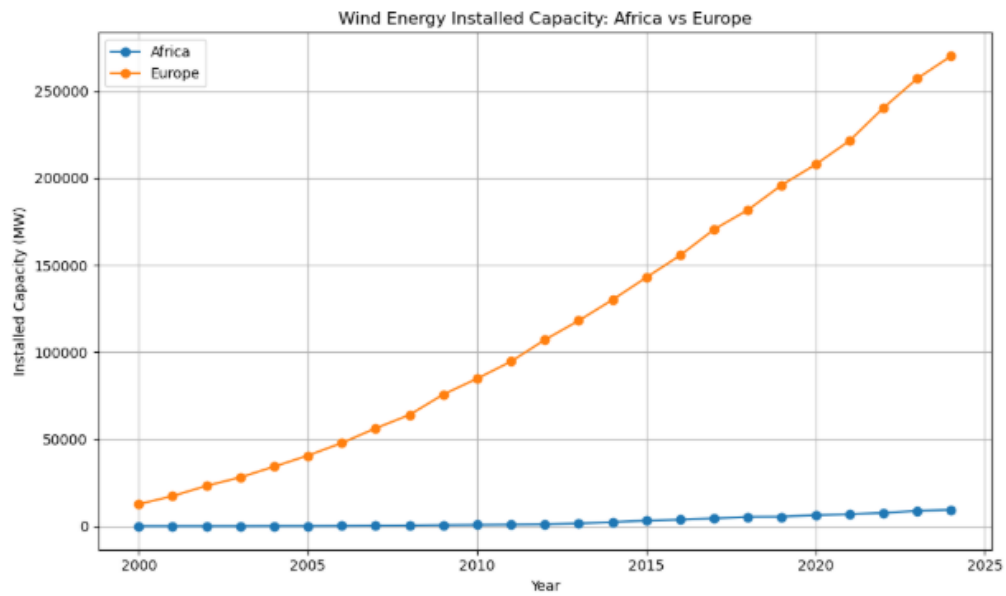


Figure 3 Wind Energy Installed Capacity of Africa against Europe

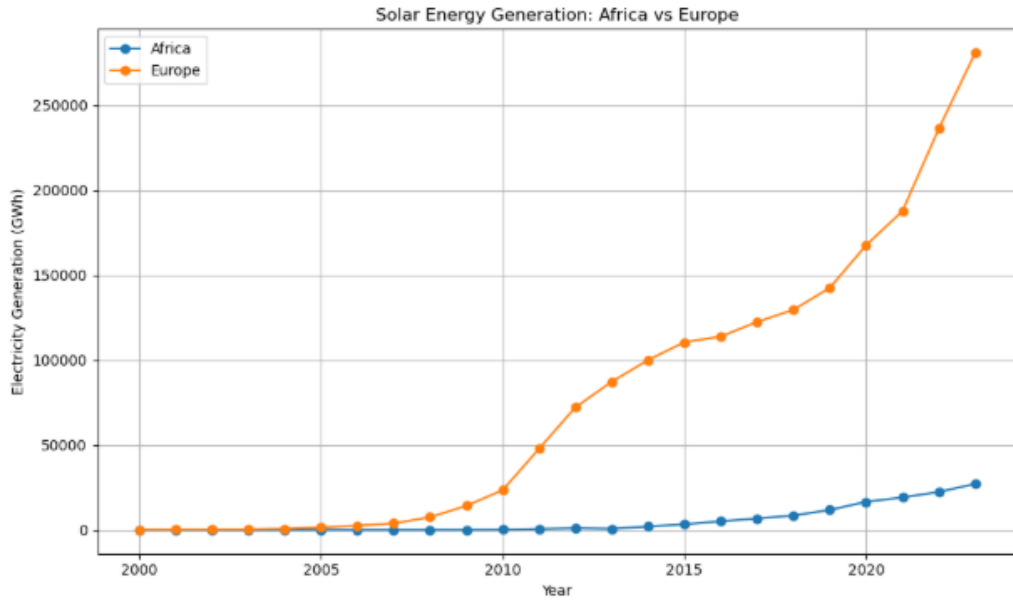


Figure 4 Solar Energy Generation of Africa against Europe

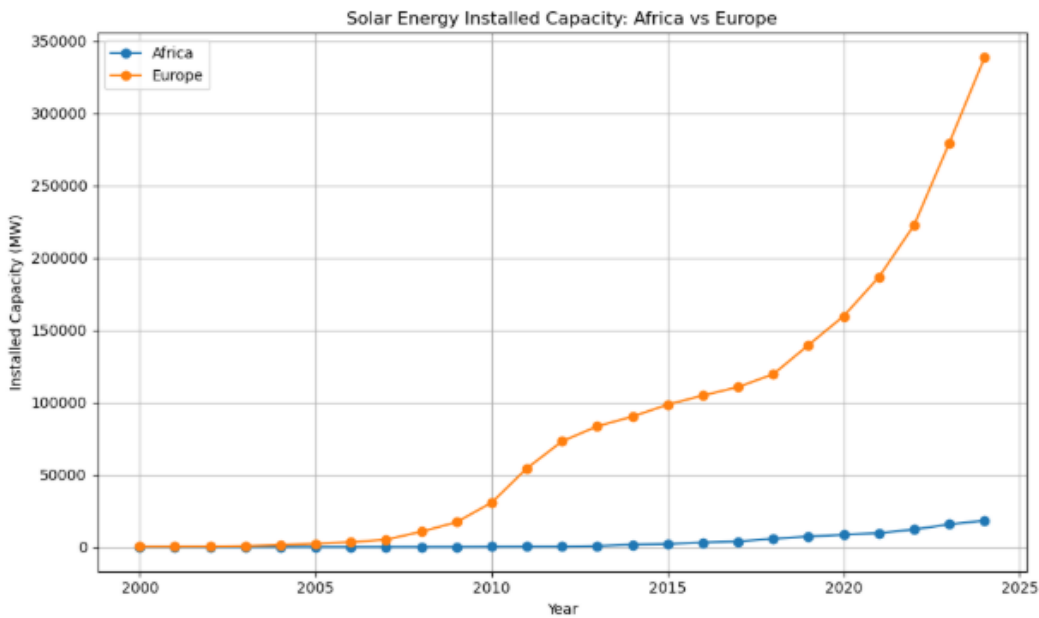


Figure 5 Wind Energy Installed Capacity of Africa against Europe

The findings show clear differences in how solar and wind perform across Africa and Europe. In Africa, solar energy demonstrates a slight edge in efficiency, with a capacity factor of 11.4% compared to Europe’s 9.7%, underscoring the continent’s stronger solar conditions despite having much less installed capacity. Wind energy tells a different story: Africa’s capacity factor of 19.3% falls behind Europe’s 25.5%, reflecting Europe’s more mature wind sector and extensive use of favorable offshore resources. Overall, the results suggest that while Africa holds a natural advantage in solar potential, Europe continues to lead in harnessing wind power at scale

Overall findings show a widening gap in renewable energy deployment between Africa and Europe. As compared to Europe, illustrating brisk energy generation and installed capacity growth through private investment, innovation, and supportive regulatory regimes, Africa's inaction mirrors challenges such as insufficient funding, poor infrastructure, and lower rates of adoption of sustainable energy technologies.

Table 1: Solar and Wind Energy of Africa vs Europe in 2024

Region	Source	Installed Capacity (MW)	Generation (GWh)	Maximum Possible Generation	Capacity Factor (%)
Africa	Solar	25000	25000	219000	11.4
Africa	Wind	8800	15000	77,584	19.3
Europe	Solar	330000	280000	2890800	9.7
Europe	Wind	260000	580000	2277600	25.5

4.2 Country-level Comparisons

Looking beyond the continental picture, country-level analysis gives a clearer sense of how Africa’s renewable energy efforts compare with global leaders. Using a Python function built in Jupyter Notebook with pandas, I was able to select any African country and compare it directly with the Big 5—Germany, Spain, Denmark, China, and the United States—across different renewable energy indicators. This allowed me to move from broad generalizations to more specific insights into how individual countries are performing.

The results reveal a striking imbalance. Take Egypt, for example. When renewable electricity output (GWh) and renewable energy consumption (TJ) are compared, Egypt’s values remain almost flat over the 25-year period, barely registering against the scale of the Big 5. By contrast, Germany, Spain, Denmark, China, and the United States all show steady growth, backed by heavy investment, infrastructure expansion, and strong policy frameworks. The comparison (Figure 5) makes the contrast stark: while the Big 5’s renewable energy output and consumption climb year after year, Egypt’s line almost disappears into the axis, reflecting the broader challenges that African countries face in scaling up generation.

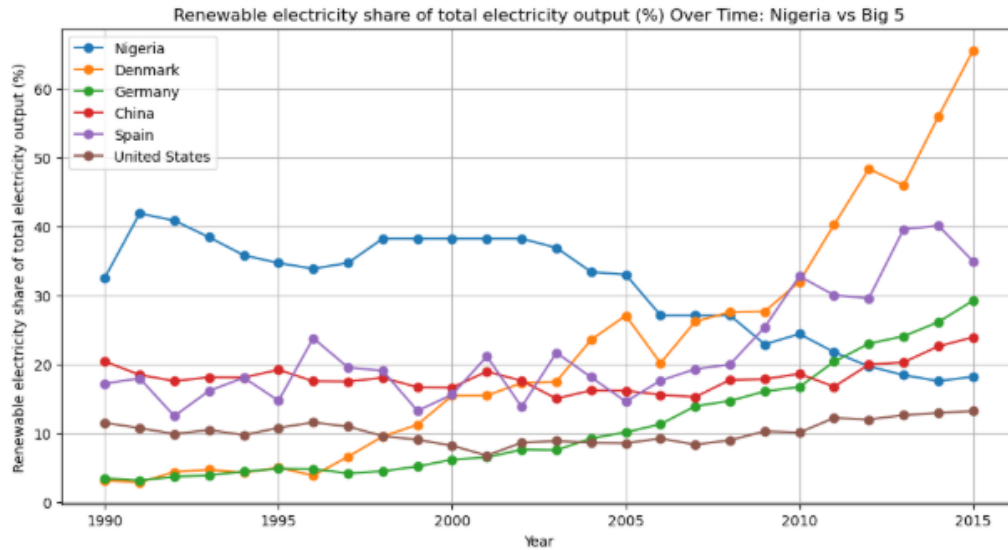


Figure 6 Renewable Energy share of total Electricity output of Nigeria vs the Big 5

The same story emerges when looking at South Africa, though in a slightly different form. For the renewable energy share of total final energy consumption (TFEC, %), South Africa's values hover between 15% and 20% over the period from 1990 to 2015. This narrow range reflects the country's heavy dependence on coal and its limited ability to diversify into renewables. By comparison, the Big 5 present a more varied and dynamic picture. China's share falls sharply from around 34% in 1990 to just 13% by 2015, as rapid industrial expansion drove higher fossil fuel use. The United States shows a gradual increase from 4% to 9%, while European leaders outperform: Denmark rises dramatically from 7% to 34%, Spain from 11% to 17%, and Germany from 2% to 14%. This comparison (Figure 7) illustrates not just the slow pace of South Africa's transition, but also the importance of long-term policy and investment in shifting a country's energy mix.

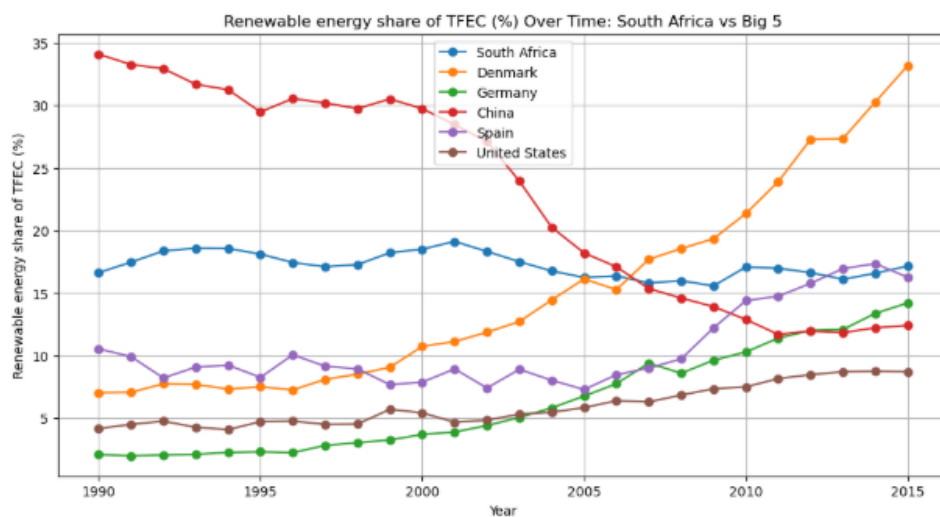


Figure 7 Renewable Energy share of Total Final Energy consumption of South Africa vs the Big 5

What stands out in these comparisons is the widening gap between Africa and global leaders. Egypt’s case highlights how underdeveloped infrastructure and weak investment leave renewable output almost negligible, while South Africa shows how even middle-income countries with stronger economies can stagnate without consistent policy support. Taken together, these findings underline that Africa’s renewable challenge is not only about resources—since the continent is richly endowed—but also about the systems and choices that determine whether those resources can be harnessed.

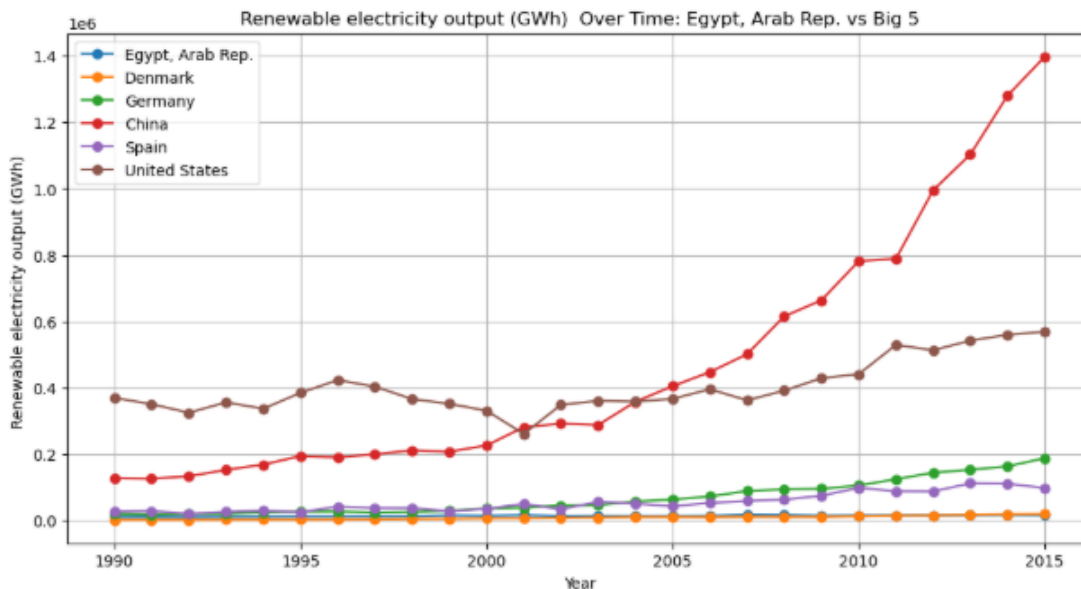


Figure 8 Renewable Energy Electricity Output of Egypt vs the Big 5

4.3 Regional Comparisons

At the regional level, the analysis did not require the construction of a specialized function; instead, countries were grouped according to their conventional sub-regions within Africa. North Africa comprises Algeria, Egypt, Libya, Morocco, Tunisia, and Sudan. West Africa includes Nigeria, Ghana, Senegal, Côte d’Ivoire, Mali, Niger, and several others. East Africa encompasses Kenya, Tanzania, Uganda, Ethiopia, Rwanda, and neighboring states. Central Africa includes Cameroon, Chad, the Democratic Republic of Congo, the Central African Republic, and Gabon, while Southern Africa covers South Africa, Namibia, Botswana, Zimbabwe, Zambia, and related countries. This classification provided a structured basis for analyzing regional dynamics in renewable energy development, recognizing that the continent’s diverse resource endowments, policy approaches, and economic structures shape energy outcomes in distinct ways.

The trajectory of renewable electricity output (measured in gigawatt-hours, GWh) between 1990 and 2015 demonstrates both common progress and stark regional disparities. North Africa increased output from approximately 1,900 GWh to just under 5,000 GWh, growth largely driven by Morocco’s proactive expansion in wind and solar energy, although Egypt and Algeria remained more reliant on gas-fired generation. Southern Africa recorded the largest increase, moving from 1,700 GWh to almost 5,500 GWh. This rise is attributable in part to South Africa’s

Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), launched in 2011, which incentivized large-scale solar and wind projects, as well as the steady role of hydropower in countries like Zambia and Mozambique. Central Africa’s more modest growth, from 1,500 GWh to 2,400 GWh, reflects a paradox: the region is endowed with abundant hydroelectric potential, particularly in the Democratic Republic of Congo, yet persistent underinvestment, political instability, and weak regional grids have hindered effective exploitation. West Africa’s marginal growth, from 1,000 GWh to 1,200 GWh, highlights challenges such as Nigeria’s dependence on natural gas, inadequate investment in grid-scale renewables, and chronic infrastructural bottlenecks. East Africa, by contrast, experienced significant progress, from 500 GWh to about 2,500 GWh, driven by Ethiopia’s massive hydropower projects (e.g., the Gilgel Gibe series) and Kenya’s leadership in geothermal development. These trajectories highlight that growth in renewable electricity output is shaped not only by natural resource availability but also by institutional capacity, policy frameworks, and the stability required to attract long-term investment.

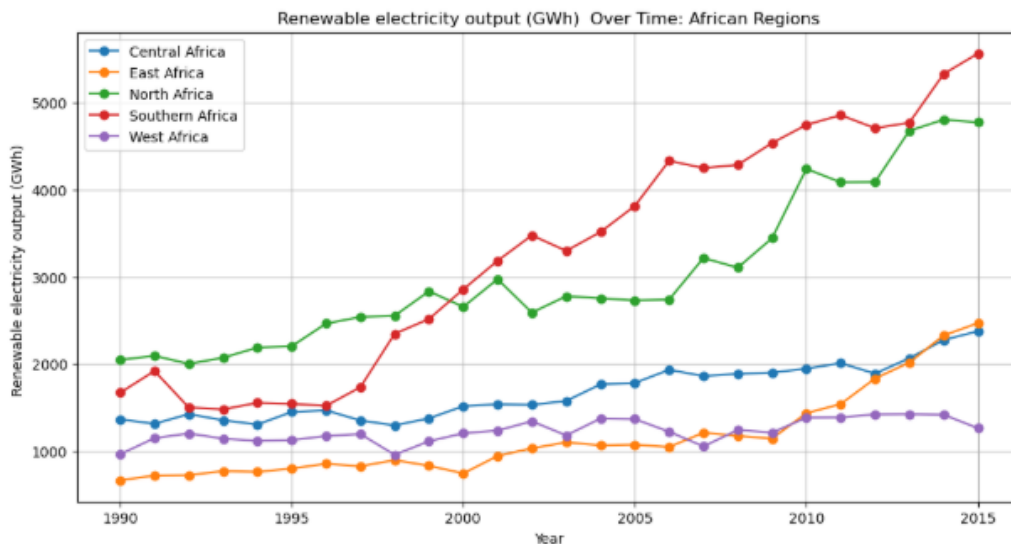


Figure 9 Renewable energy output in GWh of regions in Africa

When examining the renewable energy share of total final energy consumption (TFEC), a striking continental trend emerges: all regions witnessed a decline in renewable shares between 1990 and 2015. West Africa decreased from over 85% to 69%, East Africa from 82% to 76%, Central Africa from 85% to 70%, Southern Africa from 65% to 58%, and North Africa from 20% to 15%. Importantly, these declines do not necessarily reflect a contraction of renewable use but rather the rapid expansion of fossil fuels relative to renewables. Economic growth, urbanization, and industrialization increased demand for modern energy, often met more readily by fossil-based technologies given their existing infrastructure and international financing. In West, East, and Central Africa, the decline also indicates a slow but gradual transition away from traditional biomass (firewood and charcoal) as households increasingly seek modern alternatives. Southern Africa’s reduction reflects its coal-dominated energy system, particularly in South Africa, where coal remains the primary source of electricity despite recent renewable advancements. North Africa’s already low share illustrates its structural dependence on oil and

gas, both for domestic consumption and export, which has entrenched fossil fuels as the foundation of its energy systems.

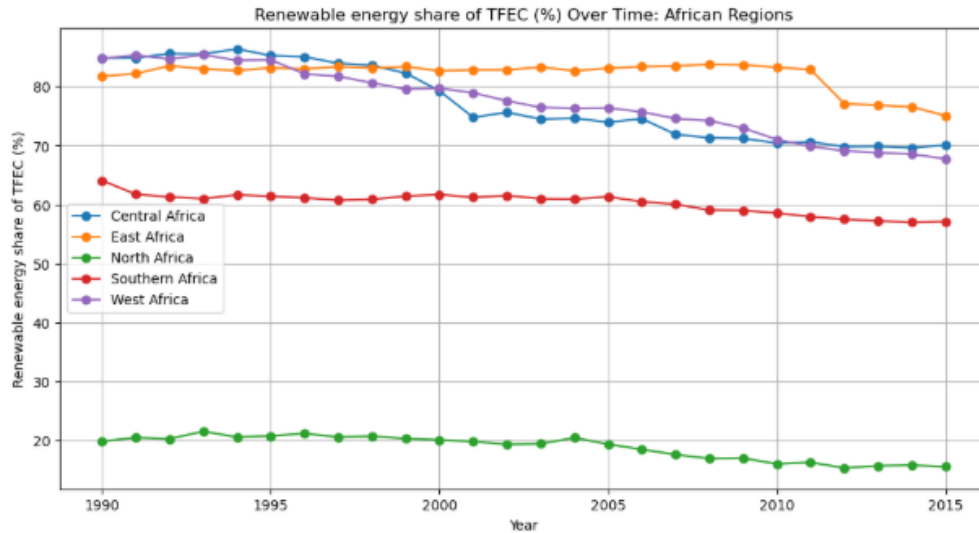


Figure 10 Renewable Energy share of TFECC over time of African Regions

Absolute renewable energy consumption, measured in terajoules (TJ), presents a different story, with all regions recording substantial increases from 1990 to 2015. West Africa expanded from around 250,000 TJ to over 450,000 TJ, largely reflecting population growth and the continued reliance on biomass as a primary energy source. East Africa doubled from 175,000 TJ to 350,000 TJ, a trajectory driven not only by population growth but also by the gradual introduction of geothermal and hydro resources into national grids. Central Africa grew from 100,000 TJ to 200,000 TJ, sustained mainly by biomass and limited hydro expansion. Southern Africa rose from 125,000 TJ to 205,000 TJ, with South Africa supplementing its coal-heavy mix with incremental renewable uptake, while other states leaned heavily on hydropower. North Africa, while showing growth from 50,000 TJ to 95,000 TJ, remained relatively small in absolute renewable consumption, underscoring its preference for fossil fuels. The relative weakness of North Africa in this area also suggests lower levels of reliance on traditional biomass, contrasting with the patterns in Sub-Saharan Africa, where traditional renewables remain deeply embedded in rural household energy systems.

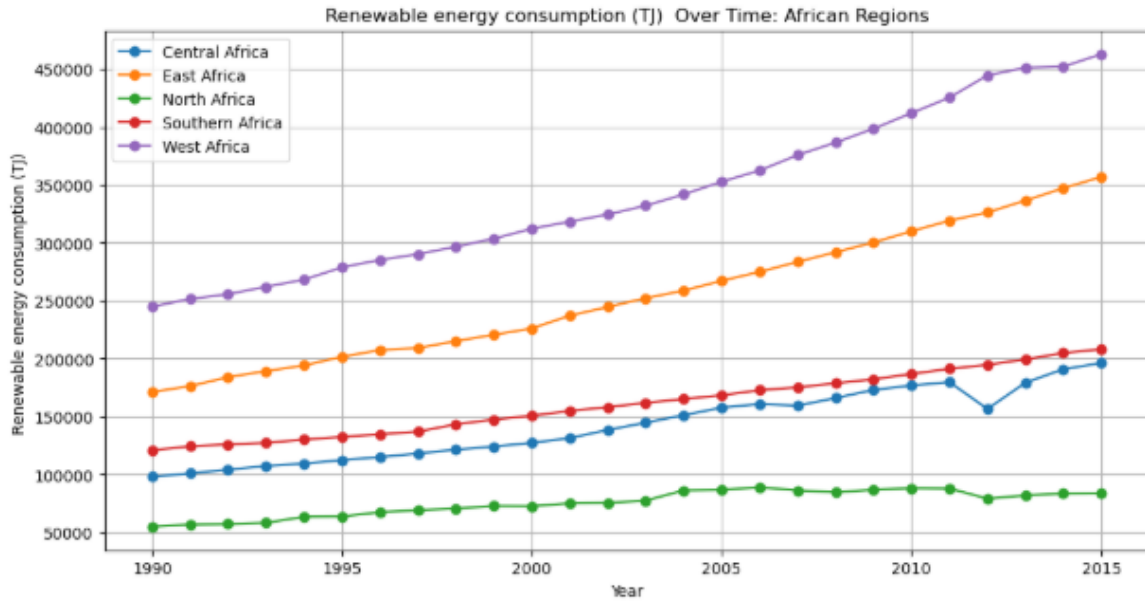


Figure 11 Renewable Energy Consumption (TJ) of Africa Regions over time.

The analysis of renewable electricity as a share of total electricity output further illustrates these structural differences. Central Africa fell slightly from 66% to 62%, despite its vast hydro resources, reflecting underdeveloped infrastructure and unmet potential. Southern Africa showed a marked increase, from 44% to 65%, supported by significant hydropower in Zambia and Mozambique and South Africa’s relatively recent diversification into renewables. East Africa, however, declined from 58% to 46%, despite the region’s notable geothermal and hydro projects; this decline may be explained by the simultaneous expansion of fossil-based capacity to meet surging demand, especially in Kenya and Tanzania. West Africa rose modestly from 28% to 32%, an outcome linked to Ghana’s hydropower investments, though broader regional dependence on oil and gas continues to limit progress. North Africa slipped from 18% to 15%, consolidating the region’s strong orientation toward fossil fuel-based electricity production.

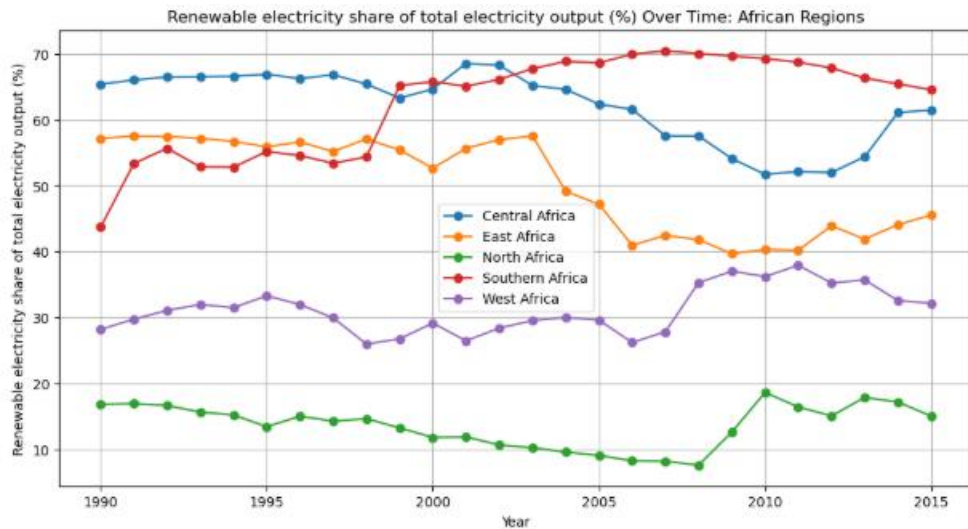


Figure 12 Renewable Electricity Share of Total Electricity Output of regions in Africa

Taken together, these findings highlight the uneven nature of Africa’s renewable energy transition. The data suggests that while renewable energy consumption has expanded in absolute terms across all regions, its share in total energy and electricity mixes has often declined or stagnated, reflecting the structural pull of fossil fuels and the growing energy demands of expanding economies. Regions like East and Southern Africa have made strategic advances through hydropower, geothermal, and more recently wind and solar, while Central and West Africa continue to rely heavily on traditional biomass, with only limited progress in modern renewable technologies. North Africa, despite its technical and financial capacity, remains locked into a fossil-fuel paradigm, with the exception of Morocco’s noteworthy progress in solar and wind. This unevenness underscores the critical importance of tailored policy interventions: investment in modern renewable technologies in Sub-Saharan Africa must be coupled with efforts to reduce dependence on traditional biomass, while in North Africa, greater diversification away from hydrocarbons is essential. Ultimately, the regional patterns demonstrate that Africa’s renewable future is not a uniform trajectory but rather a mosaic shaped by local resources, institutional capacity, and political commitment.

5. Conclusion

This study set out to examine the trajectory of renewable energy development in Africa in comparison with leading global players such as Germany, Denmark, Spain, China, and the United States, with a particular emphasis on solar and wind energy. Drawing on reliable datasets from the World Bank and the International Renewable Energy Agency (IRENA), the analysis spanned both country-level and regional perspectives across Africa between 1990 and 2015. By employing Python and Jupyter notebooks for data processing and visualization, the research highlighted stark disparities in renewable electricity generation, installed capacity, and shares of renewable energy in total consumption.

The findings reveal that Africa has made limited progress in scaling modern renewable energy technologies despite its enormous natural resource potential. At the continental level, both wind

and solar generation began at near-zero levels in 2000, mirroring Europe's starting point. However, Europe rapidly expanded its installed capacity and generation through deliberate policy support, investment incentives, and infrastructure development, while Africa's growth remained stagnant. This divergence underscores the persistence of structural challenges such as inadequate financing, weak grid systems, and a heavy reliance on traditional energy sources.

At the country level, the results highlight significant heterogeneity within Africa. For example, when comparing renewable electricity share of total output, African countries such as Egypt continue to post near-zero growth over time, while others like South Africa show modest but unstable progress. By contrast, benchmark countries in the global north registered consistent gains across the same period, reflecting their stronger institutional frameworks and higher capacity to integrate renewables. The use of a custom-built Python function further demonstrated how individual African states can be evaluated directly against global leaders, offering a powerful tool for comparative policy analysis.

Regional comparisons further expose uneven dynamics across the continent. Southern Africa showed the strongest improvement in renewable electricity share, reflecting its relatively advanced infrastructure and investments in hydro resources. West and Central Africa, while leading in absolute renewable energy consumption, remain dominated by traditional biomass use, which explains the observed declines in renewable energy shares of total final energy consumption. East Africa displayed moderate but steady gains, particularly due to geothermal and hydropower investments, while North Africa's performance highlighted stagnation in renewable energy shares despite increasing overall energy demand. Collectively, these patterns point to an urgent need for differentiated strategies that address each region's unique mix of opportunities and constraints.

The implications of these findings are profound. Africa's natural advantage in solar potential, combined with emerging opportunities in wind and hydro, positions the continent for a transformative energy transition. However, realizing this potential will require robust policy frameworks, innovative financing mechanisms, and stronger community engagement to overcome the present mismatch between resource availability and actual deployment. Without targeted interventions, Africa risks further entrenching its reliance on traditional energy sources and lagging behind in global decarbonization efforts.

This study is not without limitations. The analysis was bounded by the available data timeframe (1990–2015) and did not account for the post-2015 acceleration of renewable projects in some African states. Furthermore, the reliance on macro-level indicators means that micro-level project success factors, such as community acceptance or local governance, were not captured. Nevertheless, the methodology—combining country-level functions with regional aggregations—provides a clear and systematic approach for evaluating renewable energy trajectories.

Future research should extend this analysis to more recent years, incorporate socio-economic and policy variables, and explore geospatial datasets to better align technical renewable potential with actual deployment. Expanding the scope to include issues of equity, gender, and access will also deepen understanding of the social dimensions of Africa's energy transition.

In conclusion, while Europe and other global leaders demonstrate how sustained investment and policy commitment can accelerate renewable energy deployment, Africa remains at a crossroads. The continent's vast solar, wind, hydro, and geothermal resources offer an unparalleled opportunity to leapfrog into a sustainable energy future. Harnessing this potential will demand more than technology—it requires political will, long-term financing, regional cooperation, and inclusive policies that bring communities into the heart of the transition. With these measures, Africa can move from lagging adoption to global leadership in renewable energy.

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References

- Adebiyi, A. A., & Moloi, K. (2024). *Renewable Energy Source Utilization Progress in South Africa: A Review*. https://www.mdpi.com/1996-1073/17/14/3487?utm_source=chatgpt.com
- Adediji, Y. (2022). *A Review of Analysis of Structural Deformation of Solar Photovoltaic System under Wind-Wave Load*. Engineering Archive. <https://doi.org/10.31224/2273>
- Adediji, Y., & Adediji, A. (2024a). *An overview of Mechanical and Chemical Recycling Methods for Polyethylene Terephthalate Plastics*. Engineering Archive. <https://doi.org/10.31224/3538>
- Adediji, Y., & Adediji, A. (2024b). *Biodegradable Mg-Based Alloys for Orthopaedic Implants in Biomedical Applications*. Engineering Archive. <https://doi.org/10.31224/3537>
- Adediji, Y., Adeyinka, A. M., Yahya, D. I., & Mbelu, O. V. (2023). *A review of energy storage applications of lead-free BaTiO₃-based dielectric ceramic capacitors | Energy, Ecology and Environment*. <https://link.springer.com/article/10.1007/s40974-023-00286-5>
- Adediji, Y. B., Bamigboye, A., Aboderin, J. O., Lekwa, O. A., & Uzim, E. O. (2021). *Estimation of Global Solar Radiation on Horizontal Surfaces using Temperature-Based Model in Ilorin, Nigeria*. Engineering Archive. <https://doi.org/10.31224/osf.io/8xu69>

Adeyinka, A. M., Mbelu, O. V., Adediji, Y. B., & Yahya, D. I. (2023). A Review of Current Trends in Thin Film Solar Cell Technologies. *International Journal of Energy and Power Engineering*, 17(1).

Agoundedemba, M., Kim, C. K., & Kim, H.-G. (2023). *Energy Status in Africa: Challenges, Progress and Sustainable Pathways*. https://www.mdpi.com/1996-1073/16/23/7708?utm_source=chatgpt.com

Ajia, A. T. (2025). *Policy Challenges and Opportunities for Renewable Energy Development in Nigeria: A Systematic Review | African Journal of Environmental Sciences and Renewable Energy*.
https://afropolitanjournals.com/index.php/ajesre/article/view/660?utm_source=chatgpt.com

Anekwe, M. I. S., Akpasi, S. O., & Gaza, L. (2024). *Renewable energy investments in South Africa: Potentials and challenges for a sustainable transition—A review—Ifeanyi Michael Smarte Anekwe, Stephen Okiemute Akpasi, Mphathesithe Mzwandile Mkhize, Helper Zhou, Ranganai Tawanda Moyo, Luke Gaza, 2024*.
https://journals.sagepub.com/doi/full/10.1177/00368504241237347?utm_source=chatgpt.com

Arora, A., Kanaujia, S., & Shukla, A. (2025). *The Rise of Renewable Energy: Transforming the Global Energy Landscape*.
https://www.researchgate.net/publication/392255726_The_Rise_of_Renewable_Energy_Transforming_the_Global_Energy_Landscape?utm_source=chatgpt.com

Ashour, G. H., & Sayed, M. N. (2024). *The Role of Renewable Energy Consumption in Targeting Debt Sustainability in African and MENA Region Countries | International Journal of Energy Economics and Policy*.
https://econjournals.net.tr/index.php/ijeep/article/view/15040?utm_source=chatgpt.com

Askari, M., & Parsa, N. (2024). *A Techno-Economic Analysis of the Interconnectedness between Energy Resources, Climate Change, and Sustainable Development* (No. arXiv:2412.12235). arXiv. <https://doi.org/10.48550/arXiv.2412.12235>

Batz Liñeiro, T., & Müsgens, F. (2025). Pay-back time: Increasing electricity prices and decreasing costs make renewable energy competitive. *Energy Policy*, 199, 114523.
<https://doi.org/10.1016/j.enpol.2025.114523>

Baul, T. K., Datta, D., & Alam, A. (2018). A comparative study on household level energy consumption and related emissions from renewable (biomass) and non-renewable energy sources in Bangladesh. *Energy Policy*, 114, 598–608. <https://doi.org/10.1016/j.enpol.2017.12.037>

Bloomfield, H. C., Wainwright, C. M., & Mitchell, N. (2022). *Characterizing the variability and meteorological drivers of wind power and solar power generation over Africa—Bloomfield—2022—Meteorological Applications—Wiley Online Library*.
<https://rmets.onlinelibrary.wiley.com/doi/10.1002/met.2093>

Bogunjoko, O. (2024, December 12). *Why Nigeria's power grid keeps failing—Energy in Africa*. <https://energyinafrica.com/insight/why-nigerias-power-grid-keeps-failing/>

- Carr, W. T., Mkuhlani, S., Segnon, A. C., Ali, Z., & Zougumore, R. (2022). *Climate change impacts and adaptation strategies for crops in West Africa: A systematic review—IOPscience*. https://iopscience.iop.org/article/10.1088/1748-9326/ac61c8?utm_source=chatgpt.com
- Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy*, 2(9), 17140. <https://doi.org/10.1038/nenergy.2017.140>
- Diallo, S., Ouoba, Y., & Gatete, C. (2024). *Effect of Fossil Fuel Subsidies on Renewable Energy Transition in Sub-Saharan African Countries*. https://ideas.repec.org/h/spr/aaechp/978-3-031-52677-0_19.html?utm_source=chatgpt.com
- Dube, A., & Horvey, S. S. (2023). *Institutional quality and renewable energy capital flows in Africa | Future Business Journal | Full Text*. https://fbj.springeropen.com/articles/10.1186/s43093-023-00234-z?utm_source=chatgpt.com
- Elbarbary, S., Zaher, M. A., Saibi, H., Fowler, A.-R., & Saibi, K. (2022). *Geothermal renewable energy prospects of the African continent using GIS | Geothermal Energy*. https://link.springer.com/article/10.1186/s40517-022-00219-1?utm_source=chatgpt.com
- El-Yaqub A. B, Ibrahim Musa, & Sule Magaji. (2024). *Stock Market Indicators and Nigeria's Economic Growth: Evidence from Error Correction Model*. <https://doi.org/10.5281/ZENODO.11109315>
- Hannan, M. A., Shetwi, A., Mollik, M., & Ker, P. J. (2023). *Wind Energy Conversions, Controls, and Applications: A Review for Sustainable Technologies and Directions*. https://www.mdpi.com/2071-1050/15/5/3986?utm_source=chatgpt.com
- Hayes, K., Blashki, G., Wiseman, J., Burke, S., & Reifels, L. (2018). *Climate change and mental health: Risks, impacts and priority actions | International Journal of Mental Health Systems*. https://link.springer.com/article/10.1186/s13033-018-0210-6?utm_source=chatgpt.com
- Ikejemba, E. C. X., & Schuur, P. C. (2018). Analyzing the Impact of Theft and Vandalism in Relation to the Sustainability of Renewable Energy Development Projects in Sub-Saharan Africa. *Sustainability*, 10(3), 814. <https://doi.org/10.3390/su10030814>
- Kabutey-Ongor, M., Amenah, M. A., & Yorke, F. R. (2025). *Financial inclusion and energy poverty in Ghana: Evidence from the informal sector | Discover Sustainability*. https://link.springer.com/article/10.1007/s43621-025-01689-6?utm_source=chatgpt.com
- Lawal, A. I. (2023). *Determinants of Renewable Energy Consumption in Africa: Evidence from System GMM*. https://www.mdpi.com/1996-1073/16/5/2136?utm_source=chatgpt.com
- Levy, B. S., Sidel, V. W., & Patz, J. A. (2017). Climate Change and Collective Violence. *Annual Review of Public Health*, 38, 241–257. <https://doi.org/10.1146/annurev-publhealth-031816-044232>

- Lohmann, P. M., & Kontoleon, A. (2023). Do Flood and Heatwave Experiences Shape Climate Opinion? Causal Evidence from Flooding and Heatwaves in England and Wales. *Environmental and Resource Economics*, 86(1), 263–304. <https://doi.org/10.1007/s10640-023-00796-0>
- Mbelu, O. V., Adeyinka, A. M., Yahya, D. I., Adediji, Y. B., & Njoku, H. (2024). Advances in solar pond technology and prospects of efficiency improvement methods. *Sustainable Energy Research*, 11(1), 18. <https://doi.org/10.1186/s40807-024-00111-5>
- Meierrieks, D. (2021). Weather shocks, climate change and human health. *World Development*, 138, 105228. <https://doi.org/10.1016/j.worlddev.2020.105228>
- Meo, S. A., Shafi, K. M., & Hussain, A. (2025). The psychological cost of climate change: Anxiety among adolescents and young adults - a cross-sectional study. *Frontiers in Psychiatry*, 16. <https://doi.org/10.3389/fpsy.2025.1422338>
- Millstein, D., O’Shaughnessy, E., & Wiser, R. (2024). Climate and air quality benefits of wind and solar generation in the United States from 2019 to 2022. *Cell Reports Sustainability*, 1(6), 100105. <https://doi.org/10.1016/j.crsus.2024.100105>
- Njema, G. G., Ouma, R. B. O., & Kibet, J. K. (2024). A Review on the Recent Advances in Battery Development and Energy Storage Technologies. *Journal of Renewable Energy*, 2024(1), 2329261. <https://doi.org/10.1155/2024/2329261>
- Obah-Akpowoghaha, N. G., Tarro, M. L., Bah, M., & Mendy, S. (2022). *Climate Change and the African Union’s Role in the International System: A Brief Situational Analysis* | *Journal of African Union Studies*. <https://journals.co.za/doi/abs/10.31920/2050-4306/2022/11n1a2>
- Oladimeji, I., Adediji, Y., Akintola, J. B., Afolayan, M. A., Ogunbiyi, O., Ibrahim, S. M., & Olayinka, S. Z. (2023). *Design and Construction of an Arduino—Based Solar Power Parameter-Measuring System with Data Logger*. | *Arid Zone Journal of Engineering, Technology and Environment*. <https://www.ajol.info/index.php/azojete/article/view/243809>
- Pappis, I. (2022). *Strategic low-cost energy investment opportunities and challenges towards achieving universal electricity access (SDG7) in forty-eight African nations—IOPscience*. https://iopscience.iop.org/article/10.1088/2634-4505/ac7900?utm_source=chatgpt.com
- Serdeczny, O., Adams, S., Baarsch, F., & Commou, D. (2017). *Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions* | *Regional Environmental Change*. <https://link.springer.com/article/10.1007/s10113-015-0910-2>
- Shrestha, A., Rana, L. B., Singh, A., Phuyal, S., Ghimire, A., Giri, R., Kattel, R., Karki, K., & Jha, S. K. (2019). Assessment of electricity excess in an isolated hybrid energy system: A case study of a Dangiwada village in rural Nepal. *Energy Procedia*, 160, 76–83. <https://doi.org/10.1016/j.egypro.2019.02.121>
- Sokona, Y., Mulugetta, Y., & Gujba, H. (2012). Widening energy access in Africa: Towards energy transition. *Energy Policy*, 47, 3–10. <https://doi.org/10.1016/j.enpol.2012.03.040>

Stern, D. (2017). *The environmental Kuznets curve after 25 years* | *Journal of Bioeconomics*.
<https://link.springer.com/article/10.1007/s10818-017-9243-1>

Tseou-Nkokoane, S., Mosabala, T. D., & Kali, M. (2023). *Full article: Community imaginaries, participation and acceptance of renewable energy projects – substituting the quicksand of development with rocky fundamentals*.

https://www.tandfonline.com/doi/full/10.1080/23311886.2023.2292755?utm_source=chatgpt.com

Wang, Q., Zhang, F., & Li, R. (2023). Revisiting the environmental kuznets curve hypothesis in 208 counties: The roles of trade openness, human capital, renewable energy and natural resource rent. *Environmental Research*, 216, 114637. <https://doi.org/10.1016/j.envres.2022.114637>

Zhang, J., Ji, W., Yuan, Z., & Yuan, Y. (2023). Pyrolysis, combustion, and fire spread characteristics of the railway train carriages: A review of development. *Energy and Built Environment*, 4(6), 743–759. <https://doi.org/10.1016/j.enbenv.2022.07.001>