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# Renewable energy market in Africa: Opportunities, progress, challenges, and future prospects

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A R T I C L E  I N F O

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A B S T R A C T

The transition to renewable energy is crucial for addressing Africa's rising energy demand while fostering sustainable development. With abundant renewable resources such as solar, wind, hydropower, and biomass, Africa is uniquely positioned to play a key role in the global low carbon energy transition. This study investigates the role of renewable energy in supporting Africa's Nationally Determined Contributions (NDCs) and its alignment with the Paris Agreement's climate goals. Using a combination of empirical methodologies, including market analysis and cost-benefit evaluations, we assess the potential of renewable energy to reduce greenhouse gas emissions, alleviate energy poverty, and promote economic growth. Our findings show that harnessing just 25 % of Africa's renewable energy potential could significantly reduce energy poverty, contributing to a sustainable, low-carbon future. Furthermore, we highlights the declining costs of renewable energy technologies, driven by innovation, economies of scale, and market dynamics, making renewable energy increasingly competitive with traditional energy sources. This has led to lower consumer energy prices, improved market attractiveness, and enhanced profitability for renewable energy investments. By examining the socio-economic impacts of renewable energy adoption, the study provides key insights into the market dynamics, investment potential, and policy implications for accelerating Africa's renewable energy transition. Our findings suggest that targeted investments in renewable energy could drive a just transition, improve energy access, and foster long-term socio-economic development across the continent.

## 1. Introduction

Despite possessing immense untapped energy potential in both fossil fuels and renewable resources, Africa grapples with limited electricity generation capacity and inadequate infrastructure, creating a critical paradox in its journey toward sustainable energy [1]. This paradox underlies the region's social and economic challenges, where an unreliable electricity supply impedes development. As of 2022, Africa's total primary energy consumption stood at 20.26 Exajoules, with Sub-Saharan Africa poised to contribute significantly to this consumption due to rising living standards and decreasing energy poverty [2]. Yet, this region remains home to the majority of the global population without access to electricity, with an expected population of 2.5 billion people by 2050, of which 80 % would be in Sub-Saharan Africa. Increased access to renewable energy sources can promote economic growth, job creation, and environmental management [3]. The International Energy Agency estimates a 4 % increase in the number of people without modern energy sources between 2019 and 2021 in Sub-Saharan Africa. This highlights the urgent need for a strategic shift in energy policy, particularly towards renewable sources like solar, wind, hydropower, biomass, and geothermal energy [4].

Almost eight out of ten individuals lacking access to electricity

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worldwide reside in Africa [6], and if the status quo remains unchanged, 595 million Africans will remain without access to electricity by 2030 [7]. The World Health Organization (WHO) reported that approximately 15 % of healthcare facilities in the sub-Saharan Africa (SSA) region lack access to power supply [8]. Fig. 1 illustrates that Africa is one of the least electrified continents in the world, with over 500 million people living without access to electricity [5]. To effectively tackle these challenges, it is imperative to invest in the energy sector in Africa. Africa will require an annual energy expenditure of roughly $25 billion by 2030 to carry out the aforementioned energy improvements, according to estimates provided by the IEA [9]. This cost is a modest fraction of the global energy investment pool, equivalent to the capital cost of constructing a singular large-scale Liquefied Natural Gas (LNG) terminal.

Africa still has a lot of untapped energy potential, both in terms of fossil fuels and renewable energy sources and there is potential to increase both foreign investment and revenue from the export of fossil fuels, especially natural gas [10]. Likewise, Africa has optimal renewable energy resources like hydropower, geothermal, wind, and solar energy. Despite this fact, only 1.7 % of global solar capacity is deployed [11], which makes it even more crucial to prioritize sustainable energy production in plans for industrialization and economic expansion [12]. This requires more investment and financing to ensure that more people have access to energy in vital areas like health care and education [13]. Rehabilitation-related initiatives and funding should be used to accelerate the larger shift towards green energy as a crucial component for building a strong society. Renewable energy sources such as solar, wind, hydropower, biomass, and geoelectric are becoming more popular due to the continent's enormous potential and the need to address energy-related issues, electrify remote areas, slow down climate change, and improve energy availability [14]. According to World Health Organization (WHO), one-third of the world's population (2.4 billion people), is estimated to rely on fossil fuels like coal and natural gas for heating and cooking [15]. Approximately 3.2 million premature fatalities are reported yearly because of air pollution, primarily attributed to the use of inefficient stoves in areas lacking adequate ventilation [16].

The literature on renewable energy in Africa reveals a complex interplay of challenges and opportunities that are critical for sustainable energy development in the region. Oyewo et al. [17] propose a rationale and recommendation for Africa to achieve highly renewable energy systems, emphasizing the need for periodic optimization based on technological advancements and cost assumptions. This aligns with the findings of Ekechukwu et al. [18]. Who discusses the multifaceted challenges and opportunities in achieving universal electricity access, underscoring the necessity for integrated approaches for oil and gas sector operations. Recent works have further emphasized the critical importance of renewable energy in addressing the contemporary energy crisis and achieving social, environmental, and economic sustainability. For example, Farghali M. et al. [19] outlined strategies for mitigating energy poverty through energy-saving measures in their work. Similarly, they discussed the socio-economic impacts of integrating renewable energy into the electricity sector in another study [20]. This is particularly relevant as Africa grapples with rising energy demands driven by population growth and urbanization, which necessitate a shift towards sustainable energy solutions [20]. The potential for renewable energy to drive economic growth is also evident in Kumba's review [21], which asserted that renewable energy is a significant driver of economic development, particularly in Eastern and Central Africa. The exploration of hydrogen as a renewable energy source presents new opportunities for Africa. Saleh [22], discussed the continent's potential to develop a robust clean hydrogen industry, which could not only enhance energy security but also create millions of jobs by 2030. This aligns with the findings of Ayorinde [23], who emphasized the importance of climate finance strategies in supporting renewable energy projects across Africa, thus facilitating the transition to a low-carbon economy. Despite these advancements, significant gaps remain in the literature regarding Africa's role in achieving the targets set by the Paris Agreement and NDCs. The integration of renewable energy into existing energy systems poses challenges related to intermittency and grid stability, as noted by Chidolue et al. [24]. Additionally, the need for supportive policies that encourage private investment in renewable energy is critical, as highlighted by Ngcobo R. and Wet M. [25], who argued for the development of non-punitive policies to foster financial support for renewable energy projects in South Africa.

While existing studies have focused on various aspects of renewable energy in Africa, such as investment opportunities, challenges to universal energy access, and pathways to carbon reduction, significant gaps exist in literature. Specifically, there are limited research studies on the role of renewable energy in helping African countries meet their NDCs and net-zero goals under the Paris Agreement. Much of literature fails to explore the intersection of renewable energy development with Africa's unique socio-economic context, such as energy poverty alleviation, job creation, and regional economic development. These gaps are critical, as understanding the broader socio-economic impacts of renewable energy adoption in the context of Africa's energy challenges is crucial for creating sustainable energy policies. This study seeks to address these gaps by providing a comprehensive analysis of how Africa can leverage its renewable energy resources to meet both climate goals and sustainable development objectives.

This study contributes significantly to the literature on renewable energy in Africa by offering a comprehensive approach that integrates technical, socio-economic, and policy perspectives on renewable energy adoption. Unlike earlier studies that tend to emphasize the technical or

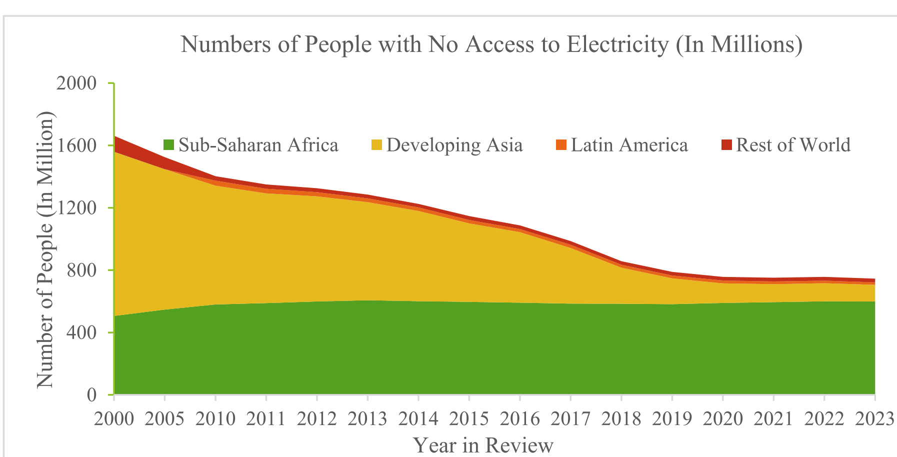


**Fig. 1.** Number of global populations with No access to electricity (2000–2023), (per region) [5].

financial dimensions, this paper provides a broader view of how Africa's renewable resources, can serve not only to achieve climate targets but also to foster economic growth, create jobs, and improve living standards in rural and underserved areas. By highlighting renewable energy's role in meeting Africa's Paris Agreement obligations and NDCs, the study underscores how these resources can alleviate energy poverty while advancing broader development objectives, including poverty reduction, health improvement, and climate change mitigation. The paper's novelty lies in its synthesis of these dimensions, offering new insights into renewable energy's potential within Africa's energy transition, beyond merely reducing emissions.

Another key contribution is our focus on policy and investment strategies. We provide actionable recommendations for governments, international bodies, and private investors, emphasizing the importance of international support, private sector involvement, and strategic public-private partnerships in accelerating renewable energy adoption across the continent. This study identifies key barriers, such as financing gaps, technical capacity constraints, and policy challenges; and proposes practical solutions to address these issues. We focus primarily on Sub-Saharan Africa, home to the majority of the continent's energy-poor population. While this offers valuable insights into the region's energy challenges, it also limits the scope by concentrating on solar, wind, hydropower, and biomass, excluding other potentially important resources like geothermal and tidal energy. This narrower focus may affect the generalizability of some of the findings.

By combining empirical techniques such as data analysis, market research, and policy reviews, this study offers a well-rounded assessment of renewable energy's potential in Africa. This mixed-methods approach integrates both quantitative analyses, like energy consumption statistics and resource potential evaluations, and qualitative insights, such as policy reviews and case studies from leading nations like South Africa and Kenya. This balanced methodology provides a nuanced understanding of how renewable energy can reshape Africa's energy landscape and drive socio-economic development. Data for this research are drawn from reputable sources, renewable energy development reports, and case studies from key African countries, ensuring both the relevance and accuracy of the findings. We emphasize the need for clear and supportive policies, increased financing, and enhanced regional cooperation to address the barriers hindering renewable energy development.

The subsequent sections of this paper are organized as follows: Section 2 provides an in-depth analysis of the current state of renewable energy in Africa, including key resources and major projects. Section 3 evaluates the trends and trajectory of renewable energy investments and demand across the continent. Section 4 examines the rationale for the adoption and implementation of sustainable energy sources in Africa, considering economic, social, and environmental factors. Section 5 outlines actionable recommendations to promote the development and scalability of renewable energy technologies in both urban and rural contexts. Finally, Section 6 concludes the study by summarizing key findings, identifying limitations, and proposing areas for future research to enhance Africa's renewable energy landscape.

## 2. The current landscape of renewable energy in Africa

While the adoption of renewable energy is increasing, with wind and solar growing at the fastest rates (currently 8 % of generation), fossil fuels still dominate 71 % of the energy supply [26]. This slow transition may hinder decarbonization goals and limit the widespread availability of renewable energy. Harnessing these resources has the potential to drive economic growth and mitigate environmental impacts from fossil fuel use [27,28]. Table 1 highlights key African nations, their energy sources, and future energy capacity.

**Table 1**
Summary of studies on African Countries' renewable energy sources, and its potential renewable energy capacity.

| Reference | Technology | Country | Capacity (MW) |
|---|---|---|---|
| Saifaddin Galal [29] | Solar | Algeria | 22000 |
| A. Laaroussi et al., [30] | Solar | South Africa | 8400 |
| N. E. Benti et al., [31] | Hydropower | Ethiopia | 4330 |
| N. E. Benti et al., [32] | Biomass | Ethiopia | 3810 |
| S. Elbarbary et al., [33] | Geothermal | Kenya | 3300 |
| Natalie Cowling [34] | Wind | South Africa | 3103 |
| Andritz [35] | Hydropower | Mozambique | 2185 |
| Remeredzai et al., [30] | Solar | Morocco | 2000 |
| Saifaddin Galal [36] | Wind | Egypt | 1643 |
| Relief Web [44] | Wind | Morocco | 1556 |
| Min. of Energy Dev [37]. | Hydropower | Kenya | 800 |
| Mordor Intelligence [38] | Solar | Ghana | 500 |
| State Dept. Energy [39] | Biomass | Kenya | 493 |
| ITA [40] | Wind | Kenya | 436 |
| Carlo Cariaga [41] | Geothermal | Tanzania | 200 |
| Int. Trade Admin [42] | Solar | Kenya | 172 |

### 2.1. Solar energy

Due to Africa's advantageous location and climate, the continent has an abundant and easily accessible solar energy resource [43]. This unique advantage allows for the widespread deployment of solar panels and solar water heaters to generate electricity and provide hot water for residential and industrial applications [44,45]. For instance, South Africa can generate 42,243 TWh of solar photovoltaic electricity and 43, 275 TWh of concentrated solar power per year [46]. In most of South Africa, where solar radiation averages 220 W/m$^2$, over 2500 h of sunshine are available annually. According to the German Aerospace Centre, solar farm spanning just 0.3 % of North Africa, could meet all of Europe's electrical needs, which is twice the current Africa's energy demand [47].

As shown in Fig. 2, solar energy shows remarkable growth, particularly solar PV, which began at approximately 0.5 GW in 2015, climbing to 20 GW by 2025. This demonstrates Africa's heavy reliance on solar PV as the centrepiece of its renewable energy strategy. Meanwhile, solar thermal capacity grew at a slower but steady pace, starting near zero in 2015 and reaching 5 GW by 2025, indicating a growing interest in diversifying solar technologies. South Africa emerges as the dominant contributor to solar capacity in Africa, followed by Egypt and Morocco, which also have significant investments in solar projects. Other countries, including Ethiopia, Tunisia, Algeria, DR Congo, and Kenya, show smaller but gradually increasing contributions, signifying a broader adoption of solar energy across the continent. This highlights solar PV as the leading renewable energy source driving Africa's energy transition [48].

Table 2 highlights that Africa's northern and southern advantageous location within the Sunbelt region contributes to its abundant solar energy resources. Egypt and South Africa exhibit the highest photovoltaic power output, ranging from 4.76 to 5.74 kWh/kWp and 4.00–5.66 kWh/kWp, respectively. Direct normal irradiation, critical for solar thermal systems, is highest in South Africa (4.19–8.50 kWh/m$^2$) and Egypt (5.25–7.85 kWh/m$^2$), indicating strong solar energy generation potential across these regions [50].

Table 3 presents Africa's top ten largest solar power projects highlighting the leading contributions from South Africa, Egypt, and Morocco.

### 2.2. Wind energy

The development of wind energy in Africa is promising due to the continent's extensive coastlines and elevated topographies, which provide favourable conditions for wind power systems. Countries such as South Africa, Egypt, and Kenya have taken the lead in harnessing wind

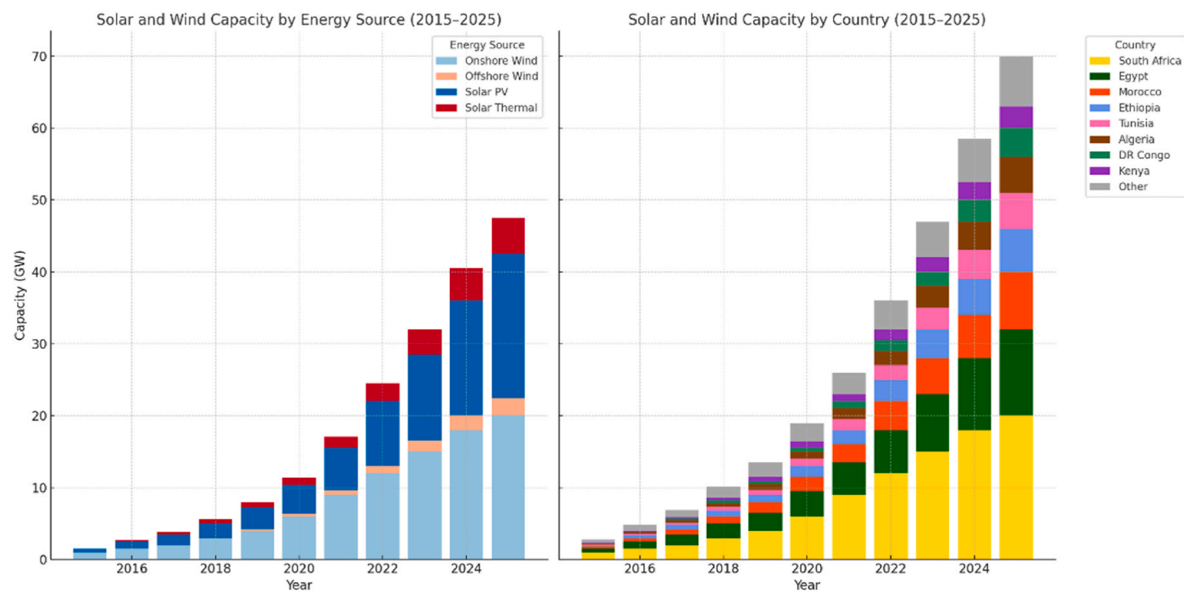


**Fig. 2.** Solar and Wind capacity growth in specific African countries [49,49].

**Table 2**
Photovoltaic Power and direct normal irradiance per day [50].

| | Algeria | Egypt | Libya | Morocco | South Africa |
|---|---|---|---|---|---|
| Photovoltaic Power Output (kWh/kWp) | 4.19–5.50 | 4.76 -5.74 | 4.76 -5.57 | 4.33–5.54 | 4.00–5.66 |
| Direct Normal Irradiation (kWh/m2) | 4.41–6.97 | 5.25–7.85 | 5.31–6.82 | 4.52–7.20 | 4.19–8.50 |

**Table 3**
Africa's ten largest solar power projects [45].

| S/N | Country | Project Name | Capacity (MW) |
|---|---|---|---|
| 1 | Egypt | Benban solar complex | 1.8 GW |
| 2 | Morocco | Noor Ouarzazate Solar complex | 580 MW |
| 3 | South Africa | De Aar photovoltaic solar plant | 175 MW |
| 4 | South Africa | Xina Solar One | 100 MW |
| 5 | South Africa | KaXu Solar One project | 100 MW |
| 6 | South Africa | Kathu Solar Park | 100 MW |
| 7 | South Africa | Ilanga Solar Power | 100 MW |
| 8 | South Africa | Jasper Solar Power Project | 96 MW |
| 9 | South Africa | Lesedi Solar PV project | 80.51 MW |
| 10 | South Africa | Kalbult solar PV plant | 75 MW |

energy potential along their coastlines [51]. However, it is important to note that Africa's wind energy potential is not as high as that of Europe [52] and other regions with higher wind energy potential such as Iceland, Lithuania, Germany, and Turkey [53,54]. The study by Zeng et al. [55], highlighted the distribution of wind power capacity in various countries, emphasizing the potential for significant wind power projects in Africa. Furthermore, the study by Adeyeye et al. [56], emphasized the challenges of utilizing wind energy in Africa due to the prevalent low wind speeds, especially in sub-Saharan Africa. This suggests that wind power projects in Africa may face unique technical and operational considerations. Moreover, the research by Pullinger et al. [57]. provided insights into the young but growing wind industry in South Africa, indicating the increasing focus on wind energy projects in the region. The study by Umoh and Lemon [58], highlights the substantial growth of wind installed capacity in South Africa, further underlining the country's prominence in the African wind power landscape. Considering the potential for offshore wind energy, the study by Rae and Erfort [59] show the offshore wind energy production potential in the Southwestern African region, particularly Namibia and west of South Africa, indicating the possibility of major offshore wind power projects in the region. In addition, the study by Sawadogo et al. [60] emphasized the importance of renewable energy, including wind energy, for the development of African countries, indicating a growing focus on renewable energy projects in the region. This suggests that while onshore wind energy potential may be limited in certain African regions, offshore wind power presents a viable alternative for harnessing wind energy.

As depicted in Fig. 2, an upward trajectory for wind energy, with onshore wind dominating the capacity outlook across Africa. Starting at approximately 1 GW in 2015, onshore wind steadily rises to about 20 GW by 2025, reflecting significant investments in this renewable energy source. In contrast, offshore wind was almost zero until 2019, after which it began to grow gradually, reaching about 2.5 GW by 2025. This indicates that offshore wind projects are less prominent in this region compared to onshore wind, due to higher costs, technological constraints, and infrastructure challenges. The wind capacity growth is primarily driven by countries like South Africa and Egypt, with South Africa maintaining its position as the leader in onshore wind development throughout the period [48]. Table 4 highlights Africa's top ten largest wind power installations, showcasing their capacities, locations, and current status.

**Table 4**
Africa's ten largest wind power installations [61].

| S/N | Country | Project Name | Capacity | Status |
|---|---|---|---|---|
| 1 | Kenya | Lake Turkana Wind Farm | 310 MW | Completed |
| 2 | Morocco | Tarfaya Wind Farm | 301 MW | Completed |
| 3 | Egypt | Ras Ghareb | 262.5 MW | Completed |
| 4 | Egypt | Lekela Power | 250 MW | Planned |
| 5 | Ethiopia | Adama I & II Wind Farm | 204 MW | Completed |
| 6 | Morocco | Akhfenir Wind Farm | 200 MW | Completed |
| 7 | Senegal | Taiba N'Diaye wind farm | 158 MW | Completed |
| 8 | South Africa | Khobab & Loeriesfontein 2 Wind Farms | 140 MW/ farm | Completed |
| 9 | South Africa | Kangnas Wind Farm | 140 MW | Completed |
| 10 | Mauritania | Boulenouar Wind Farm | 102 MW | Planned |

### 2.3. Hydropower

Africa's extensive coastlines and elevated landscapes contribute to an annual average flow of 17.7 $m^3/s$, making the region highly conducive for the utilization of hydropower, a renewable energy source that has been harnessed for decades [62]. Hydropower currently constitutes around 17 % of electricity generation in Africa, with several countries, including the Democratic Republic of the Congo, Ethiopia, Malawi, Mozambique, Uganda, and Zambia, relying on it for over 80 % of their electricity needs [63]. Africa's hydroelectric capacity is substantial, with landmark projects such as the Grand Inga Dam projected to add 6,450 MW of capacity, making it one of the most ambitious renewable energy undertakings on the continent [56]. By 2040, hydropower's contribution is expected to rise to 23 %, playing a pivotal role in the transition to sustainable energy [49].

However, while hydropower offers clean energy, it comes with notable environmental and social trade-offs that require careful consideration. The construction of large dams often leads to the displacement of communities, as seen in projects like the Gibe III Dam in Ethiopia, where thousands of residents were relocated. Furthermore, hydropower projects can significantly impact biodiversity, as river ecosystems are altered, fish populations disrupted, and wetlands flooded. For example, the Aswan High Dam in Egypt has affected sediment flow, altering agricultural productivity downstream. Climate change further complicates these dynamics, as shifting rainfall patterns and prolonged droughts threaten the reliability of hydropower plants, especially in regions with seasonal water flow variability.

As shown in Fig. 3, the aging infrastructure of many African hydropower facilities, coupled with climatic stressors, is projected to reduce the capacity factor of plants by an estimated 3 percentage points between 2060 and 2099, compared to the baseline period of 2010–2019 [49]. This decline poses a critical challenge for countries heavily dependent on hydropower, necessitating the need for investments in modernization and diversification of energy sources. A balanced approach, incorporating integrated water resource management, equitable resettlement policies, and biodiversity conservation measures, is crucial to ensuring that hydropower remains a sustainable and socially responsible energy solution for Africa [64].

### 2.4. Biomass and bioenergy

Biofuels like green diesel, biogas, biodiesel, and ethanol made from wood fuel, charcoal, timber pellets, crops, forestry residue, and industrial and municipal waste continue to be the most commonly used energy sources in Africa [65]. Even if there are not many huge-scale biogas facilities in Africa yet, there is still a lot of untapped potential [66]. Tumwesige et al. [64,67] emphasized the significant potential of biogas utilization in rural regions of Sub-Saharan Africa. Africa possesses a forest cover of 650 million hectares, constituting approximately 17 % of the global land surface. The geographical extent of the covered area is one-fifth of the continent [68]. However, it is important to note that the dissemination of this particular resource is characterized by an uneven pattern. Several African nations, including Kenya, Zimbabwe, South Africa, Tanzania, Ghana, and Ethiopia, have adopted the utilization of biomass products as an alternative source of energy, with forest biomass, leftovers, and various other forms of waste resources [69].

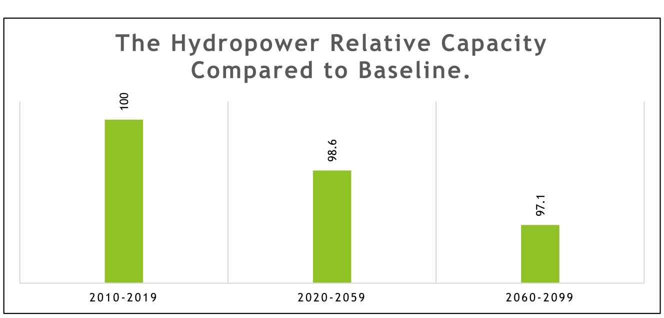


**Fig. 3.** Hydroelectric Capacity Factor Trends in African Plants (2010–2019 vs. 2020–2099) [49].

According to Dasappa [71], African forests provide an average of 0.85 ha per person in terms of forest area. Around 1 % of the its landmass is classified as forest, although tropical rainforests constitute approximately 25 % of global forested regions. In light of the limited availability of up-to-date information, this study presented forest product statistics for some African countries using data from the Food and Agriculture Organization (FAO), as shown in Table 5. Africa's forests and woody areas cover around 645 million hectares or 21 % of the continent's total geographical area. These regions are distinguished by a notable abundance of biomass cover [72].

**Table 5**
Areas of forest and woods in Africa [70].

| African Region | Area of Forest Land (1000 ha) | Area of Land (%) | Area with Woods (1000 ha) | Area with Trees (1000 ha) |
|---|---|---|---|---|
| North Africa | 131,048 | 8.6 | 94,609 | 10,207 |
| East & South Africa | 226,534 | 27.8 | 167,023 | 10,345 |
| West & Central Africa | 277, 829 | 44.1 | 144,468 | 788 |
| Total | 645, 412 | 21.4 | 406,100 | 21,339 |

### 2.5. Geothermal energy

Geothermal energy have potential in Africa but remains underutilized despite the continent's vast resources. Table 6 outlines the ultra-high-temperature rock energy potential in selected African countries at depths of 7.5 km, 10 km, and 12.5 km, categorized by region. It highlights geothermal energy resources in East, West, Central, and Southern Africa, with the highest potential found at 12.5 km depths in countries like Sudan, Ethiopia, and Chad. This data underscores the vast untapped geothermal potential across the continent, particularly in East Africa's Rift Valley region [73]. Kenya leads the continent with about 630 MW of geothermal power capacity, representing over 40 % of the country's electricity production [74]. The Olkaria Geothermal Plant is a major success story, positioning Kenya among the top ten countries globally in geothermal power generation. With expansion plans to increase capacity to over 1,000 MW by 2025, Kenya demonstrates that geothermal energy can be a viable and sustainable solution, given adequate investment and supportive policies [75].

Challenges including high upfront exploration costs, which can range from $10 million to $20 million per project, and the need for improved transmission and distribution infrastructure are major barriers to the development of this technology [76]. Fragmented regulatory frameworks across the continent also hinder large-scale geothermal development, limiting the ability to fully tap into Africa's geothermal potential. Despite these challenges, the Industry Base-case projects moderate growth, driven by improved policies and financing, while the Ambitious Case forecasts the potential for 17 GW of geothermal capacity by 2050 with more aggressive investments [77]. Beyond the East African Rift, there is untapped geothermal potential in the Southern Africa region, where countries such as South Africa, Zambia, and Namibia could benefit from emerging technologies like Enhanced Geothermal Systems (EGS). EGS, which creates geothermal reservoirs in areas without natural hydrothermal resources, could unlock new opportunities for geothermal development [78].

Additionally, Ocean Thermal Energy Conversion (OTEC) is an emerging technology that could complement geothermal energy in Africa, especially for island nations and coastal regions [79]. OTEC utilizes

**Table 6**
Ultra hot Rock Energy Potential in Africa by Country, Depth, and Region [73].

| Africa Country | Region | 7.5 km Depth (GW) | 10 km Depth (GW) | 12.5 km Depth (GW) |
|---|---|---|---|---|
| Tanzania | East Africa | 0 | 0 | 50 |
| Burundi | East Africa | 0 | 0 | 100 |
| Mozambique | Southern Africa | 0 | 0 | 100 |
| Rwanda | East Africa | 0 | 0 | 50 |
| Eritrea | East Africa | 0 | 0 | 100 |
| Djibouti | East Africa | 0 | 0 | 100 |
| Kenya | East Africa | 0 | 0 | 200 |
| Angola | Southern Africa | 0 | 0 | 100 |
| South Sudan | East Africa | 0 | 0 | 100 |
| Somalia | East Africa | 0 | 0 | 100 |
| Cameroon | Central Africa | 0 | 100 | 200 |
| Nigeria | West Africa | 500 | 700 | 800 |
| Ethiopia | East Africa | 600 | 900 | 1000 |
| Niger | West Africa | 200 | 400 | 600 |
| Chad | Central Africa | 800 | 1000 | 1200 |
| Sudan | North Africa | 1000 | 1200 | 2000 |

the temperature difference between warm surface waters and colder deep ocean waters to generate electricity. The African Union's Agenda 2063 [80] identifies ocean energy as a potential source for diversifying Africa's renewable energy mix. Although OTEC is still in the experimental phase, countries like Mauritius and Seychelles have started exploring its feasibility, with pilot projects in the pipeline. According to recent studies, Mauritius could potentially generate up to 60 MW of electricity using OTEC, significantly contributing to its renewable energy goals [81].

### 2.6. Mineral resources

As the world shifts away from fossil fuels, renewable technologies such as solar and wind energy, paired with energy storage solutions like lithium-ion batteries, are being adopted widely [82]. Lithium-ion batteries have proven to be highly effective in meeting energy demands across various applications, including portable electronics, electric vehicles, and grid storage [83]. Lithium-ion batteries dominate the electric vehicle (EV) market, comprising about 49 % of the global rechargeable battery market. Minerals essential for their production—lithium, cobalt, manganese, nickel, and graphite—are found in abundance in several African countries, including the Democratic Republic of Congo (DRC), Zambia, South Africa, Madagascar, Mozambique, Tanzania, and Gabon [84]. For instance, the DRC holds an estimated 6.6 million tonnes of lithium reserves, making it a significant global supplier [84]. Similarly, Nigeria, with its large population and growing adoption of electric mobility, is emerging as a potential market for lithium-ion batteries [85].

Africa holds approximately 30 % of the world's mineral resources, which are vital for renewable energy technologies [86]. Beyond lithium, other minerals such as cobalt, nickel, manganese, and copper are critical for the production of batteries, solar panels, and wind turbines [87]. Fig. 4 summarizes the distribution of key mineral reserves across African nations, underscoring the continent's central role in the global energy transition. The DRC leads in cobalt production, while Zambia and South Africa contribute significantly to global copper and manganese supplies [88]. These resources are integral to the manufacturing of clean energy infrastructure and are vital for achieving energy security.

While Africa's mineral wealth offers significant opportunities, it also presents challenges. The extraction of these resources often has environmental and social consequences, such as land degradation, pollution, and conflicts with local communities. Addressing these issues requires a sustainable approach to mining that balances economic benefits with environmental preservation and community welfare [89]. The growing demand for minerals like lithium, cobalt, and nickel has also drawn attention to their scarcity. As demand increases, industries are exploring alternative materials and improving recycling methods to reduce dependence on raw mineral extraction [90]. Recycling and urban mining are gaining importance as strategies to ensure a steady supply of these materials [90]. Lithium prices have risen sharply in recent years, reaching over £61,000 per tonne in 2022 compared to £4,600 in 2020 [91]. This increase reflects the rising demand for EV batteries and energy storage systems. By 2050, the demand for metals such as cobalt, lithium, and nickel is projected to grow by 500 %, driven by the

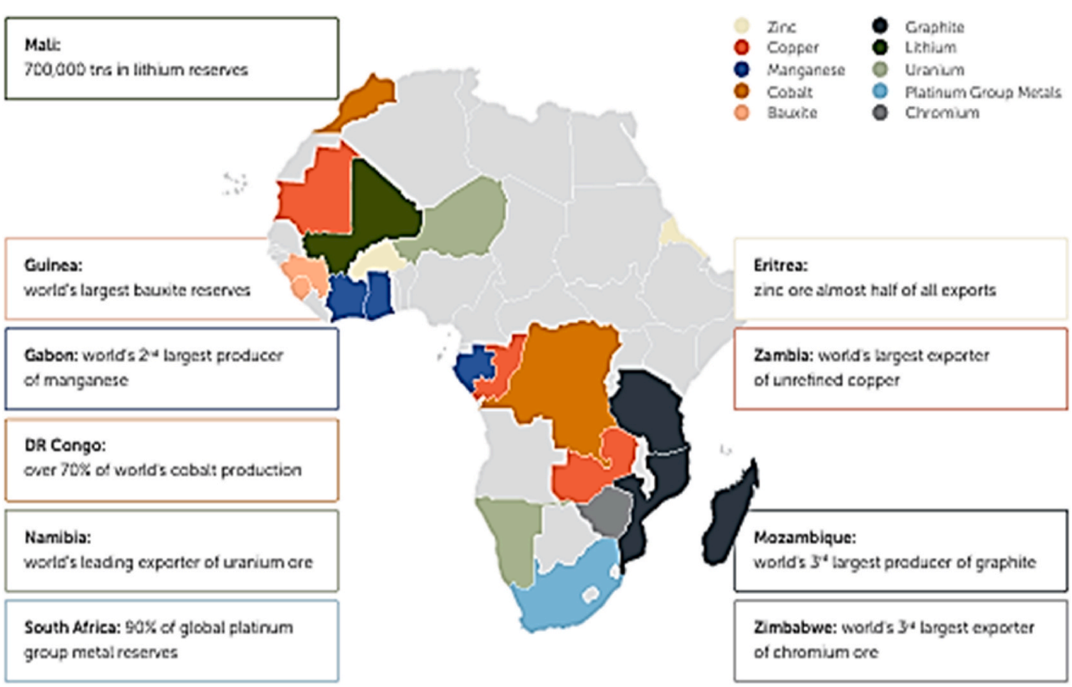


**Fig. 4.** Distribution of key low-carbon minerals across Africa [88].

expansion of renewable energy systems and electric mobility [92].

### 2.7. Scalability of renewable energy technologies: Urban vs. rural contexts

The scalability of renewable energy in Africa presents both opportunities and challenges, shaped by significant disparities in electrification between urban and rural areas. Fig. 5 illustrates this regional divide, showing that over 80 % of North Africa's population has electricity access, compared to less than 30 % in Sub-Saharan Africa (SSA). Urban areas in African nations typically enjoy higher electrification rates, often exceeding 70 %, while rural areas lag far behind, often below 20 %. For instance, Cape Verde achieves near-equal electrification in urban (95 %) and rural (95 %) areas, while Sierra Leone's rural electrification rate is just 2 % compared to 52 % in urban regions. Urban centers like Johannesburg, Nairobi, and Cairo lead renewable energy adoption through projects like Cairo's Benban Solar Park (1.8 GW) and Nairobi's Olkaria Geothermal Plant (700 MW). However, expanding urban systems will require substantial investments, with the IEA estimating a need for $50 billion annually in Sub-Saharan Africa by 2030 to improve grid flexibility, energy storage, and infrastructure [93].

In rural areas, where over 600 million Africans lack electricity access, decentralized renewable energy systems such as solar home kits and microgrids offer practical solutions [94]. These systems provide power for essential services like healthcare and education, as seen in Nigeria's Rubitec Solar microgrid, which powers over 500 households and businesses [95]. Despite their potential, rural electrification faces significant challenges, including high mini-grid costs, averaging $0.55/kWh, compared to the global average of $0.35/kWh. Seasonal income variability and logistical difficulties further threaten the financial sustainability of these projects. For instance, Burkina Faso, where 70 % of the population is rural, has an electrification rate of just 4.7 %, highlighting the scale of the challenge. Cape Verde's 95 % rural electrification rate demonstrates how strong governance and targeted investments can overcome these barriers [93].

The urban-rural divide reflects decades of unequal energy infrastructure investment. While urban areas in Senegal and Nigeria, enjoy electrification rates exceeding 70 %, rural areas often remain below 10 %. Bridging this gap will require tailored approaches [93]. Urban areas must prioritize grid modernization, smart grids, and energy storage innovations, while rural areas will benefit from decentralized solutions and realistic tariff benchmarks [96]. To accelerate rural electrification, public-private partnerships and international aid have facilitated

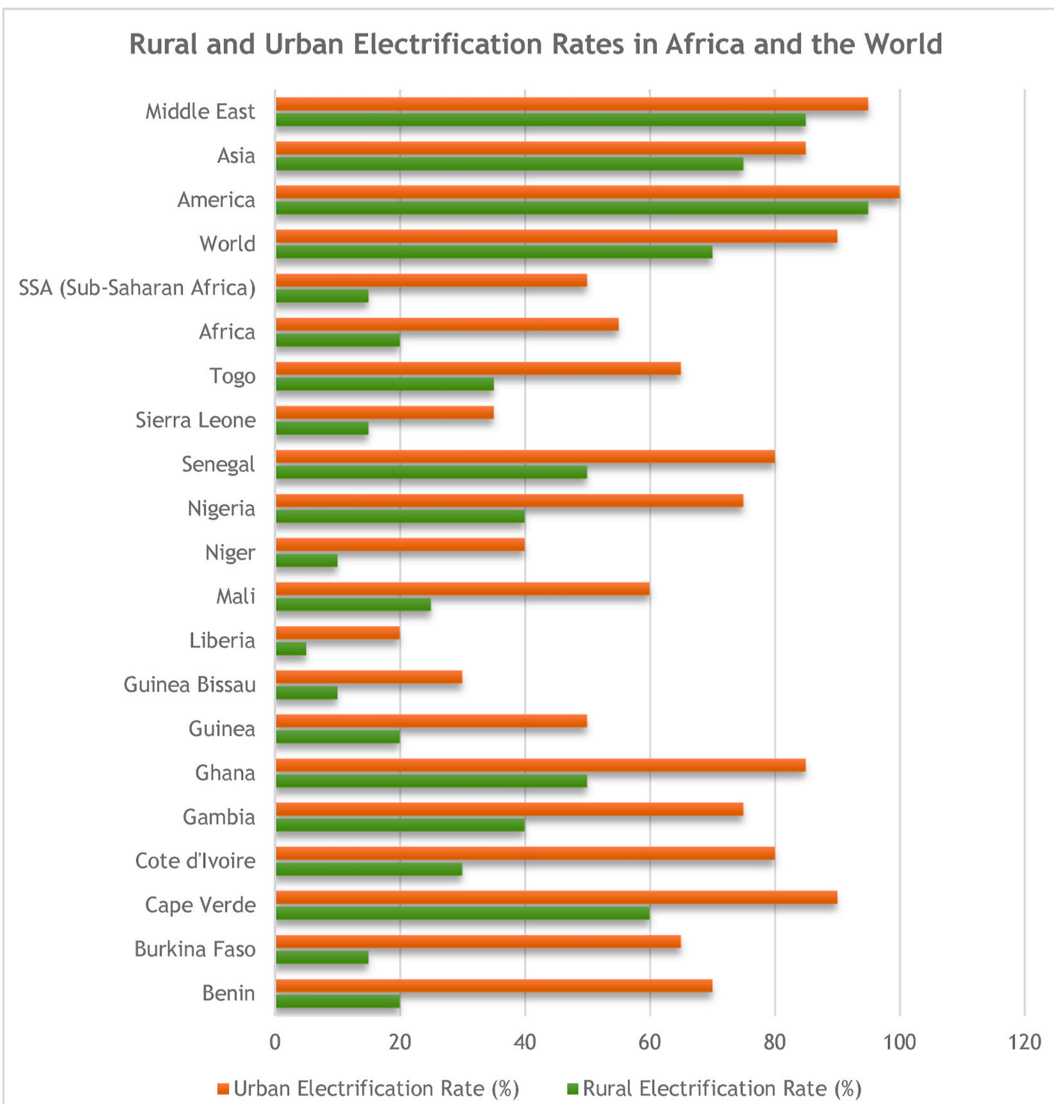


**Fig. 5.** Electrification rates in rural and urban areas across selected African countries, regions, and global averages, highlighting disparities in access to electricity [93].

off-grid projects like mini-grids and solar home systems. For example, Ghana, where 70 % of the rural population is electrified, showcases the potential of such interventions when combined with effective planning and investment [97].

As electricity demand continues to grow due to population increases and economic development in SSA, renewable energy must serve as the foundation of Africa's energy strategy [98]. Addressing rural infrastructure gaps and leveraging decentralized renewable systems will enable Africa to bridge the electrification divide. By capitalizing on its abundant solar, wind, and geothermal resources, coupled with international support and innovative financing mechanisms, Africa has the potential to achieve widespread energy access and drive transformative socio-economic progress [99].

### 2.8. *Africa's share in global renewable energy investment landscape*

Following the COVID-19 pandemic and the Russian invasion of Ukraine, the energy sector and global economy have faced significant disruptions, forcing countries to re-evaluate their energy policies [100]. These crises have disproportionately affected emerging and developing economies, particularly in Africa, where energy security and financial stability are pressing concerns. Policymakers, businesses, and households are prioritizing energy independence and sustainability to mitigate rising global energy costs and supply chain [101,102] vulnerabilities [103] shift, which aligns with the urgent need to address climate change. Globally, organizations like the IEA have pledged significant investments, including USD 2 trillion allocated for clean energy upgrades in 2024, signalling a shift toward a new energy economy. However, Africa, despite its growing energy needs, will receive only USD 40 billion, just 2 % of the total clean energy investment globally, further emphasizing the continent's financial disadvantageous position in transitioning to sustainable energy [104].

Between 2016 and 2030, Africa's clean energy investments have been steadily increasing, but the region is behind global trends, as illustrated in Fig. 6 [105]. Surveys indicate that USD 110 billion is spent annually on the African energy market, of which USD 70 billion is allocated to fossil fuels, surpassing renewable energy investments. This disparity highlights the continent's urgent need for increased funding to scale up renewable projects and reduce dependence on fossil fuels [106]. By comparison, major economies like China are expected to receive USD 675 billion, followed by Europe (USD 370 billion) and the United States (USD 315 billion) in 2024 alone, due to their exponential growth in electric vehicles and clean energy infrastructure [107]. For Africa to achieve a meaningful energy transition, increased investments in renewable technologies and infrastructure are crucial, particularly as raw material price hikes threaten to raise capital costs for key projects by 15–25 % compared to 2020 [108]. Despite these challenges, renewable energy remains the most affordable option for new electricity generation globally, offering Africa an opportunity to align with sustainable energy goals while addressing its unique energy challenges [109].

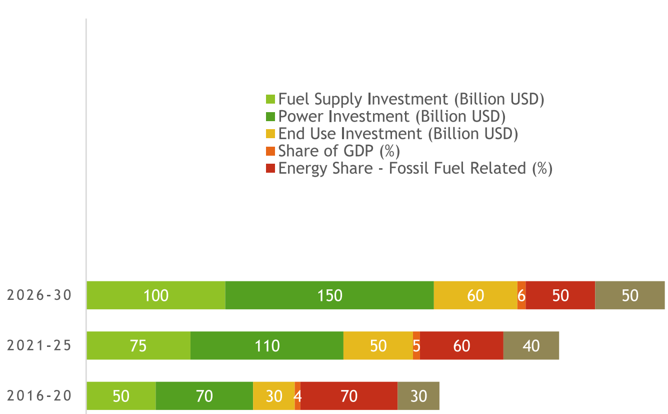


**Fig. 6.** Projected clean energy investments in Africa (2016–2030): Allocation by sector, share of GDP, and energy type [105].

### 2.9. *Aligning Africa's renewable energy market with global energy transition trends: opportunities and lessons*

Africa's renewable energy market, while still developing, holds significant potential to align with global energy transition trends. The continent possesses 10 % of the world's wind potential and 40 % of its solar potential, yet only accounted for 47 GW of global renewable capacity in 2021, compared to the global total of 2,800 GW [110]. Morocco's Noor Ouarzazate Solar Complex (580 MW) and Kenya's Lake Turkana Wind Power Project (310 MW) exemplify Africa's progress but also highlight the vast untapped potential [111]. As renewable energy continues to be a global priority, Africa's vast resources position the continent as a key player in meeting global decarbonization goals. The global trend of decentralization in energy systems presents both challenges and opportunities for Africa. Mini-grids and off-grid solar solutions are becoming critical to improving energy access for the 600 million Africans without electricity [112]. Africa's decentralized energy solutions mirror global moves toward distributed generation seen in Europe and the U.S., where smart grids and energy storage have transformed grid management. The adoption of smart grid technologies in Africa, while still in its infancy, could significantly enhance the integration of renewable energy into national grids, addressing challenges of energy variability and grid reliability [113].

#### 2.9.1. *Comparative analysis of energy costs*

Economic competitiveness plays a pivotal role in aligning Africa's renewable energy market with global trends. Globally, the cost of renewable energy has fallen dramatically in recent years. Between 2010 and 2021, the levelized cost of electricity (LCOE) for utility-scale solar PV dropped by 88 %, and for onshore wind by 68 %, and the LCOEs have even reduced further since then, making renewables the cheapest power generation option in most regions [114]. In Africa, solar PV and wind now outperform coal and gas in cost-competitiveness, offering a pathway to reduce electricity prices while increasing energy access. A global comparison of electricity costs further underscores the potential for renewable energy to improve affordability in Africa. Fig. 7 illustrating the global electricity costs reveals significant disparities, with average electricity prices in countries like Germany ($0.323 per kWh) and Japan ($0.211 per kWh) being far higher than those in regions with abundant renewable energy resources, such as Russia ($0.050 per kWh) and China ($0.084 per kWh) [115]. Africa can leverage its vast renewable energy potential to achieve cost reductions similar to those observed in China, where large-scale deployment of solar PV and wind has driven down energy costs significantly [115].

Countries like Germany and China provide clear examples of how renewable energy adoption can drive down costs. Germany's Energiewende, through sustained investment and policy incentives, has significantly reduced the cost of wind and solar energy while ensuring their competitiveness against fossil fuels [116]. Similarly, China's large-scale deployment of solar PV, which reached 330 GW by 2021, has been instrumental in driving global cost reductions [117]. Africa, with its abundant natural resources and rapidly declining renewable energy costs, is well-positioned to follow these examples to attract foreign investments, reduce electricity prices, and improve energy access. Lower electricity costs driven by renewables also carries socio-economic benefits. Affordable electricity enhances energy access for underserved populations, promotes industrial development, and reduces reliance on costly and polluting fossil fuels. By addressing investment barriers and scaling renewable deployment, Africa can unlock these benefits and position itself as a leader in the global energy transition [118].

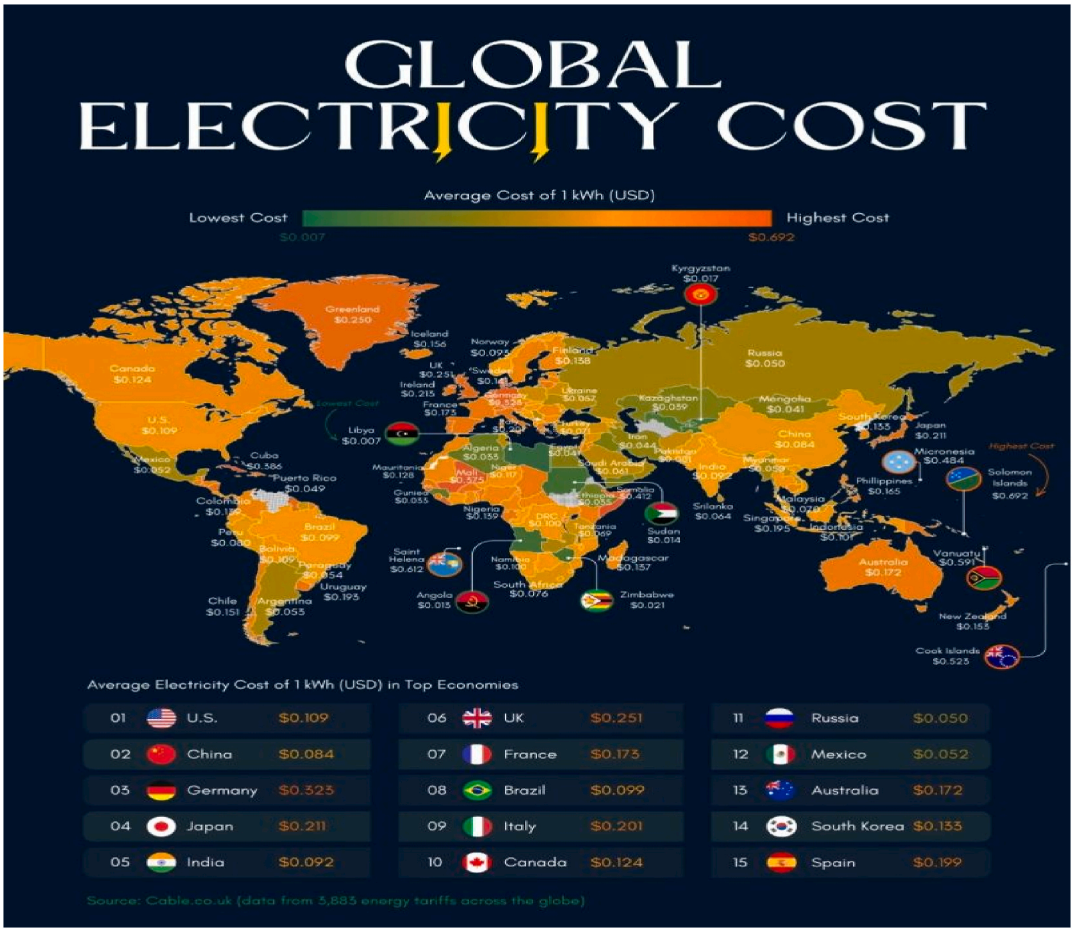


**Fig. 7.** Comparative Overview of Global Average Electricity Prices (USD per kwh) Highlighting Regional Disparities and Opportunities for Renewable Energy to Drive Affordability [115].

## 3. Africa's renewable electricity market analysis

In 2020, Africa's residential sector was at the forefront of electricity consumption, accounting for 14,416,372 TJ of energy consumed [119]. This high demand in the residential area underscores the urgent need for renewable energy solutions. The transportation sector followed as the second-largest energy consumer, using about 4,695,000 TJ, which highlights the potential for a substantial impact through renewable energy and electric vehicle integration [119]. The industrial sector played a considerable role, consuming around 3,513,000 TJ, further emphasizing the transition to renewable energy sources as crucial for sustainable development [119]. This context sets the stage for the Sustainable Africa Scenario's projections between 2020 and 2023, indicating a pivotal shift in energy sources. This shift is driven by decreasing costs in renewable technologies and the introduction of new policies supporting renewables.

Africa's strategic move to capitalize on its abundant renewable resources, particularly its rich solar potential, is a key component in this transition. By 2030, it is projected that solar PV and wind energy will account for 27 % of the continent's power generation. This increase in renewable power generation is not just beneficial for environmental reasons but is also critical for the operational dynamics of power systems, playing a vital role in maintaining a stable balance between supply and demand. The combined efforts in residential, transportation, and industrial sectors towards renewable energy adoption are essential for the development of a robust, sustainable, and resilient energy infrastructure in Africa. This transition is supported by the decreasing costs of renewable technologies and the implementation of policies that encourage the adoption of low-carbon energy solutions [120,121]. Africa, possessing the globe's richest solar resources, is set to significantly increase its solar and wind power generation. By 2030, these sources are projected to produce 27 % of Africa's electricity, marking an eightfold increase from 2020. Such a surge in renewable power generation holds profound implications for the functionality of power systems, particularly in maintaining the equilibrium between supply and demand [122].

### 3.1. *The demand for electricity in Africa*

Electricity demand in Africa remains high due to low access rates, with many individuals and businesses relying on costly alternatives such as diesel or petrol generators to meet their daily energy needs [122]. According to the World Bank [123], a significant portion of Africa's population lacks reliable electricity access, leading to increased energy costs and hindering socio-economic development. This underscores the market potential for electricity generation and distribution, presenting attractive opportunities for investment. Africa's residential sector was the largest consumer of electricity in 2020 followed by the transportation sector and the industrial sector (3.51 PJ) [124]. As shown in Fig. 8, by 2040, electricity consumption is projected to triple due to rising household purchasing power, increased industrialization, and supply reliability, with consumption categorized into productive demand, existing consumptive demand, and new consumptive demand [125]. This growth reflects the continent's rapid urbanization and economic expansion, projected to reach $10 trillion by 2030 and $29 trillion by 2050.

Table 7 highlights the demographic drivers of electricity demand in

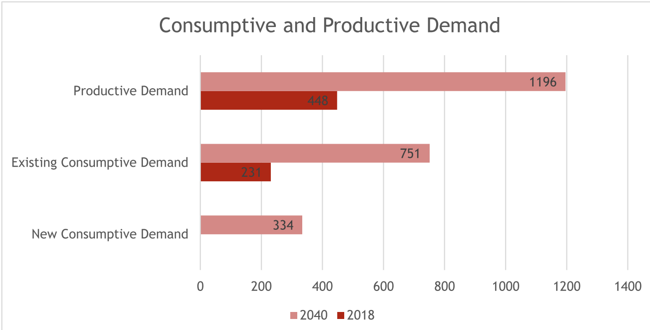


**Fig. 8.** Electricity consumption breakdown by category for the years 2018 and 2040 [125].

**Table 7**
Population dynamics in top 20 African countries [126].

| Countries | Population | % Growth | Net Migrants |
|---|---|---|---|
| Nigeria | 226,324,453 | 2.41 | −59,996 |
| Ethiopia | 128,030,971 | 2.55 | −11,999 |
| Egypt | 113,551,323 | 1.56 | −29,998 |
| DR Congo | 103,843,533 | 3.29 | −14,999 |
| Tanzania | 68,370,261 | 2.96 | −39,997 |
| South Africa | 60,700,957 | 0.87 | 58,496 |
| Kenya | 55,620,606 | 1.99 | −10,000 |
| Uganda | 49,214,074 | 2.82 | −126,181 |
| Sudan | 48,697,356 | 2.63 | −9,999 |
| Algeria | 45,924,024 | 1.57 | −9,999 |
| Morocco | 38,015,708 | 1.02 | −39,998 |
| Angola | 37,211,284 | 3.08 | −1,000 |
| Ghana | 34,431,271 | 1.93 | −9,999 |
| Mozambique | 34,349,713 | 2.81 | −5,000 |
| Madagascar | 30,670,130 | 2.41 | −1,500 |
| Cote d'Ivoire | 29,217,039 | 2.53 | 6,000 |
| Cameroon | 28,999,174 | 2.63 | −4,800 |
| Niger | 27,689,329 | 3.8 | 1,000 |
| Mali | 23,633,353 | 3.1 | −39,998 |
| Burkina Faso | 23,528,830 | 2.55 | −24,998 |

Africa's most populated countries. For example, Nigeria, with a population of over 226 million and a growth rate of 2.41 %, represents a significant share of the continent's energy needs. Similarly, countries like Ethiopia (128 million, 2.55 % growth) and the Democratic Republic of Congo (103 million, 3.29 % growth) demonstrate the link between population growth and rising energy demand [126]. These trends underscore the urgent need for sustainable electricity infrastructure to meet the demands of rapidly growing populations and urban centers. Off-grid systems are expected to play a major role in addressing Africa's electricity deficit, particularly in rural areas. Zebra et al. projected that off-grid solutions will electrify a substantial portion of the population in Sub-Saharan Africa [127]. Initiatives like the Southern African Universities Radiometric Network (SAURAN) and assessments of solar irradiance in Southern and West Africa provide critical data to support the development of solar energy projects. Such efforts will be essential in meeting the continent's growing electricity needs while mitigating the impacts of climate change on energy resources [128].

### 3.2. *Africa's investment dynamics and trends in renewable energy*

African renewable energy markets are undergoing significant transformation, reflecting a growing awareness of the sector's vast potential [129]. As shown in Fig. 9, between 2000 and 2020, approximately USD 60 billion was invested in green energy projects, excluding large hydropower [130]. Notably, over 90 % of this, or USD 55 billion, was committed between 2010 and 2020, with investments concentrated in a few countries. During this period, renewable energy investments in

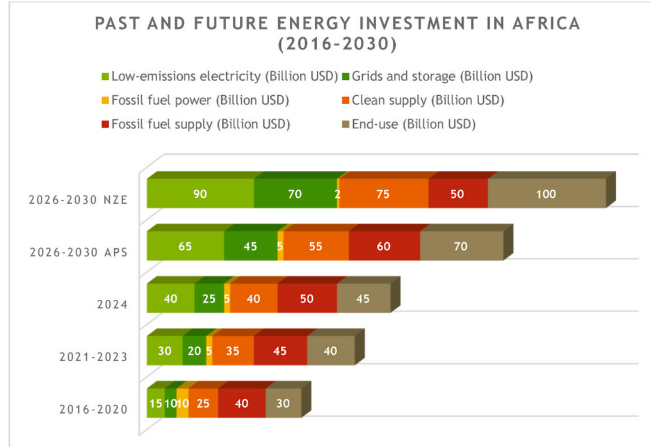


**Fig. 9.** Past and future energy investment in Africa (2016–2030) [130].

Africa grew at an impressive annual rate of 96 %, outpacing growth in Asia-Oceania (15 %) and the global average (7 %). Despite this progress, Africa received only 2 % of global renewable energy investments over the past two decades [131]. Fig. 9 reveals the past and future energy investments in Africa (2016–2030). It highlights the disparity between current trajectories and the levels required to meet net-zero targets by 2050. Under the Announced Pledges Scenario (APS), investment in low-emission electricity, grids, and clean energy supply is projected to increase but remains insufficient compared to the Net Zero Emissions (NZE) scenario, which requires significantly higher allocations to clean energy and grid infrastructure [132]. This underscores the need for greater international support, private sector participation, and strategic policies to close the funding gap and accelerate Africa's energy transition.

While renewable energy investments are gaining momentum, fossil fuels still attract substantial funding, with international companies spending over USD 5.1 billion on fossil fuel exploration in Africa in 2022 [133]. This focus on fossil fuels presents challenges to aligning with the Paris Agreement's 1.5 °C target [134,135]. However, initiatives like Kenya's inaugural Africa Climate Summit have begun calling for urgent action to scale up renewable energy investments and reduce reliance on fossil fuels [136]. In 2023, Africa's renewable energy investments reached a record $36.6 billion, marking a 12 % increase from the previous year. Despite this growth, the continent's share of global renewable energy investments remains disproportionately low, accounting for only 3 % of the total [11,137]. This highlights the ongoing need for increased investment to fully harness Africa's renewable energy potential.

#### 3.2.1. *Public-private partnerships and international support in Africa's Renewable energy development*

Africa's energy landscape faces a critical challenge, with approximately 600 million people lacking reliable electricity access [94]. To address this, the African Union has set ambitious goals to achieve universal electricity access by 2030, requiring an estimated $30 billion in initial investment to unlock over $70 billion in electrification opportunities [138]. Public-private partnerships (PPPs) have emerged as a key mechanism for bridging this funding gap, leveraging private sector innovation and public sector support to drive sustainable energy solutions across the continent [139]. PPPs bring together public and private entities to pool financial resources, technical expertise, and risk mitigation strategies. In renewable energy, these partnerships can enable scalable and cost-effective solutions. The Power Africa initiative, for instance, demonstrates the impact of such collaborations [140]. By combining public financing with private innovation, the initiative has expanded solar energy access in Tanzania, creating affordable and sustainable energy options. Similarly, Kenya's Lake Turkana Wind Power project—Africa's largest wind farm, was developed through a partnership between the Kenyan government, private investors, and international financial institutions. This project significantly increased Kenya's renewable energy capacity, created jobs, and stimulated local economic development [141].

International organizations like the Global Energy Alliance for People and Planet (GEAPP) also play a critical role in fostering Africa's renewable energy transition. These organizations offer financial instruments and guarantees to mitigate risks, making renewable energy projects more attractive to private investors [142]. Such support is particularly vital in regions where local utilities face operational or financial instability, often deterring large-scale investment. Partnerships that integrate local developers with international expertise ensure that projects remain contextually relevant while benefiting from advanced technology and de-risked financing [143]. South Africa's renewable energy auction system exemplifies this, using transparent processes to secure investment and deliver predictable returns [144].

While the potential of PPPs is significant, challenges such as currency depreciation, political instability, and weak utility performance remain obstacles to progress. Currency volatility undermines the financial sustainability of projects, while unpredictable regulatory changes deter long-term investment. Additionally, the financial instability of local utilities often jeopardizes energy supply reliability, complicating the investment landscape. Addressing these challenges requires coordinated efforts from governments, private investors, and international organizations. By fostering stronger public-private collaborations and mitigating risks, Africa can accelerate its renewable energy transition, expand electricity access, and drive sustainable economic growth [94, 142].

### *3.3. Progress, opportunities and challenges of renewable electricity market in Africa*

Africa's electricity market is primarily regulated by state-owned utilities overseeing generation, transmission, and distribution [145]. However, efforts toward privatization and market-oriented reforms have emerged in some countries to foster competition and attract private investments [146]. South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has procured over 6,000 MW of renewable energy since 2011, attracted $14 billion in private investments, and created over 30,000 jobs, demonstrating the transformative potential of liberalization [147]. In contrast, Europe and the USA, where private companies own over 50 % of renewable energy capacity, benefit from stable regulatory frameworks that encourage innovation and private-sector participation [148]. The continent's renewable energy sector faces challenges such as political instability, weak governance, and regulatory uncertainty. Recent military coups in Mali, Niger, and Burkina Faso have disrupted energy investments and increased risks such as contract enforcement issues and regulatory inconsistencies [149]. According to IRENA [150], 25 African nations lack comprehensive renewable energy policies, deterring private investors. Security risks, including civil unrest and infrastructure vandalism, disrupt over 40 % of projects, while currency volatility in countries like Zambia and Ghana further escalates costs for imported components [151,152].

Despite these obstacles, Africa's renewable energy potential is immense. With abundant solar, wind, and hydro resources, renewable energy could address energy poverty for 600 million Africans without electricity while creating over 2 million jobs by 2030 [144]. Solar and wind energy emit less than 20 $gCO_2/kWh$ over their lifetimes compared to 500 $gCO_2/kWh$ for coal, making them a sustainable alternative [143]. Addressing challenges such as land-use impacts, and critical material sustainability will be essential to ensuring the long-term success of renewable energy investments in Africa [90].

### *3.4. Successful renewables energy projects in Africa*

Table 8 summarizes the diversity of renewable energy projects in Africa and the importance of considering both their successes and challenges.

## 4. Rationale for the implementation of sustainable energy sources in Africa

### *4.1. Cost of renewable and conventional energy comparison*

According to recent studies, renewable energy remains the most affordable option for new electrical systems globally, especially in Africa [167]. Paul Akiwumi [168,169] noted that by 2030, renewables may become more affordable than 96 % of coal plants worldwide. This shift positions renewable energy as the most financially sensible choice for increasing installed capacity or modernizing aging infrastructure [170]. In 2021, nearly two-thirds of the 163 GW of newly built renewable power had lower costs than the G20's lowest coal-fired option [171]. Solar PV, now the cheapest source of electricity in Africa, is projected to outperform all other sources by 2030. The cost of wind energy has also dropped significantly since 2010, while the costs of traditional fossil and nuclear technologies have either stagnated or seen minimal reductions [94].

Recent data also highlights a major transformation in renewable energy costs between 2010 and 2023, as illustrated in Table 9. Solar PV experienced an 86 % reduction in total installed costs (from USD 5,310/kW to USD 758/kW) and a 90 % drop in its levelized cost of electricity (LCOE) (from USD 0.46/kWh to USD 0.044/kWh). Similarly, onshore wind saw a 49 % decrease in installed costs and a 70 % decline in LCOE, while offshore wind costs reduced by 48 % and LCOE dropped by 63 %. In contrast, traditional fossil fuels and nuclear power have not experienced comparable declines. From 2010 to 2021, the LCOE for large-scale renewable energy projects experienced unprecedented reductions: an 88 % decline for solar PV, 68 % for onshore wind, and 60 % for offshore wind [172].

These cost reductions have made renewables increasingly competitive with fossil fuels. However, 2022 saw temporary cost increases in some renewable energy technologies due to global supply chain disruptions. Onshore wind costs rose by 39 % to USD 0.046/kWh, while offshore wind experienced a 1.4 % increase to USD 0.076/kWh. Solar PV costs decreased by 6.25 % to USD 0.045/kWh during the same period. Encouragingly, renewable energy prices began stabilizing by the end of 2022, with reductions of 1.7 % for solar PV, 10.2 % for offshore wind, and 6.3 % for onshore wind [172]. The dramatic decline in renewable energy costs over the past decade underscores the economic viability of transitioning to clean energy systems. Investments in solar PV and wind energy, supported by ongoing technological advancements and economies of scale, position Africa to achieve cost-effective energy access while addressing climate change and fostering sustainable development.

### *4.2. Renewable energy role in enhancing energy security*

The African Development Bank underscores the critical role of renewable energy in enhancing Africa's energy security while safeguarding the environment [173]. Africa possesses an abundance of regionally dispersed renewable resources, including 10 TW of solar capacity, 350 GW of hydropower potential, 110 GW of wind energy potential, and 15 GW of geothermal energy potential [174]. These resources can collectively generate up to 24,000 TWh of electricity annually, offering sustainable and cost-effective energy solutions for the millions of Africans currently lacking access to modern energy services. By harnessing these localized renewable energy resources, African countries can significantly mitigate the risks associated with volatile fossil fuel prices, supply interruptions, and reliance on imported energy [175].

**Table 8**
Successful implemented renewable energy projects in Africa.

| Projects | Successes | Failures | Budget | Impact |
|---|---|---|---|---|
| Noor Solar Complex, Morocco | • 580 MW Generating Power Plant [153]<br>• 1000 employment opportunities<br>• 533,000 tonnes annual reduction of carbon emission [153,154]<br>• The globe's biggest concentrated solar power facility [155] | • Budget overruns.<br>• Concerns about water usage in the desert region [154]<br>• Loss of native vegetation and wildlife habitat [156] | $2 billion [155] | • Reduces carbon gas emissions,<br>• Increases energy security,<br>• Boosts economic growth,<br>• Expands electricity access<br>• Facilitates education [156] |
| REIPPP Program, South Africa | • Total generating capacity of 6.3 GW<br>• R209.4 billion private sector investment.<br>• 38,701 employment opportunities<br>• 33.2 Mton reduction of carbon emissions.<br>• Saved 39.2 million kilolitres of water [157] | Delays and disputes related to power purchase agreements and grid integration [157]. | $20.5 billion [158]. | • Electricity Supply Enhancement [159]<br>• Job Creation [159]<br>• Economic Growth [160]<br>• Facilitates Education [161] |
| Rwanda's Solar Home Systems | • 12.230 MW Total energy installed on-grid [162]. | • Private industry constraints<br>• Unaffordability for low-income households<br>• Negative regulatory adjustments [163] | $48.94 million [162] | • Electricity Supply Enhancement<br>• Job Creation<br>• Economic Growth [164] |
| Benban Solar Park, Egypt | • 1650 MW Generating Capacity<br>• World's 4th largest solar plant [165] | Concerns about land disputes and local employment issues [166]. | $4 billion [165] | • Job Creation and Skills Development [166]<br>• Economic Impact [166]<br>• Supporting National Energy Goals [165]<br>• Increased Renewable Energy Capacity [36] |

**Table 9**
Trends in Total Installed Costs, Capacity Factors, and Levelized Cost of Electricity (LCOE) for Renewable Energy Technologies from 2010 to 2023 [172].

| Technology | Total Installed Costs (2023 USD/kW) | | | Capacity Factor (%) | | | Levelized Cost of Electricity (2023 USD/kWh) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2023 | Percent Change | 2010 | 2023 | Percent Change | 2010 | 2023 | Percent Change |
| Bioenergy | 3010 | 2730 | -9% | 72 | 72 | 0% | 0.084 | 0.072 | -14% |
| Geothermal | 3011 | 4589 | 52% | 87 | 82 | -6% | 0.054 | 0.071 | 31% |
| Hydropower | 1459 | 2806 | 92% | 44 | 53 | 20% | 0.043 | 0.057 | 33% |
| Solar PV | 5310 | 758 | -86% | 14 | 16 | 14% | 0.46 | 0.044 | -90% |
| Concentrated Solar Power (CSP) | 10453 | 6589 | -37% | 30 | 55 | 83% | 0.393 | 0.117 | -70% |
| Onshore Wind | 2272 | 1160 | -49% | 27 | 36 | 33% | 0.111 | 0.033 | -70% |
| Offshore Wind | 5409 | 2800 | -48% | 38 | 41 | 8% | 0.203 | 0.075 | -63% |

Renewable energy integration also offers a pathway to reducing dependence on fossil fuels, enhancing resilience, and strengthening long-term energy security. By diversifying the energy mix, countries can reduce their vulnerability to geopolitical and market fluctuations tied to oil and gas imports [176]. For instance, Kenya, a leader in renewable energy on the continent, has committed to achieving a complete transition to renewable energy by 2030 [177]. Through measures such as revising feed-in tariffs, establishing net metering, and providing tax incentives, Kenya is enhancing the accessibility and affordability of electricity while diversifying its power supply [178]. This strategy not only decreases reliance on fossil fuels but also ensures greater grid stability by balancing intermittent sources like solar and wind with more consistent ones such as hydropower and geothermal energy [176].

Decentralized systems, such as mini-grids and off-grid solar solutions, further bolster energy reliability, especially in rural areas [179]. Modern grid technologies like energy storage and smart grids enhance stability by managing fluctuations in renewable energy supply and demand. For example, solar microgrids in East Africa have reduced reliance on diesel generators while increasing electricity access in underserved communities [179]. Kenya's White Paper on Renewable Energy envisions energy as a catalyst for decarbonized growth, targeting 100 GW installed capacity by 2040. This strategy attracts investments from businesses transitioning to clean energy, positioning Kenya as a global leader in renewable innovation [180]. By harnessing its abundant resources and adopting progressive policies, Africa can reduce fossil fuel dependency, enhance energy security, and build a resilient, sustainable energy system [181].

### *4.3. Technological and infrastructure challenges of integrating intermittent renewable energy sources*

Integrating solar and wind energy into Africa's power grids poses challenges due to variability and outdated infrastructure [182]. Renewable energy depends on environmental factors, causing fluctuations that disrupt supply-demand balance. In sub-Saharan Africa, up to 20 % of potential renewable energy is curtailed due to insufficient storage and grid flexibility [183]. Lithium-ion batteries and pumped hydro storage can store excess energy for later use, and battery costs have dropped by 97 % over the last three decades, making them increasingly viable [184]. Demand response strategies, such as incentivizing households to align energy use with peak generation, also enhance grid reliability [185].

Africa's centralized grids are poorly suited for decentralized renewables, especially in regions like Northern Kenya and South Africa's Northern Cape, which lack transmission networks to move energy to demand centers [186]. This causes bottlenecks and curtailments [183]. Smart grids, offering real-time monitoring and automated energy management, optimize renewable integration. South Africa's smart grid systems have cut transmission losses by 30 %, demonstrating their potential across the continent [187]. Projects like the Southern African Power Pool and the Ethiopia-Kenya high-voltage line, which will carry 2,000 MW, are essential for improving cross-border energy flow and reducing inefficiencies [188]. Grid instability remains a challenge as renewables expand. Without adequate backups, sudden drops in solar or wind output—during cloudy days or low wind—can destabilize grids [189]. Solutions like South Africa's 50 MW/75 MWh battery storage and Ethiopia's solar-hydro hybrid systems have shown success in stabilizing grids by balancing variability [190,191]. However, modernizing sub-Saharan Africa's energy infrastructure will require $80–100 billion over the next decade [192]. Kenya's green bond program, which raised $40 million for renewable projects, highlights how innovative financing can bridge funding gaps. By investing in storage, smart grids, and transmission infrastructure, Africa can overcome these barriers and unlock its vast renewable energy potential [193].

### 4.4. Promotes climatic Adaptation and long-term viability

Africa faces significant challenges ahead, with climate change posing one of the most severe and lasting threats [194]. According to the 2023 World Economic Forum (WEF) Global Risks Report, failure to address climate change could result in widespread displacement, food and water insecurity, and an 18 % decline in global GDP [195]. These risks are compounded in Africa by its reliance on climate-sensitive agriculture and its rich but vulnerable biodiversity [196]. An estimate of the possible impact or severity of the risks that have been discovered is shown in Table 10, considering a 2-year and a 10-year timeframe. Africa comes with significant environmental implications that require careful consideration. Lifecycle emissions from technologies like solar panels and wind turbines, though much lower than fossil fuels, are generated during production, transportation, installation, and decommissioning, often involving the energy-intensive extraction of rare earth elements and other critical materials [197]. A life cycle assessment (LCA) approach is essential to quantify these emissions and improve sustainability [198]. Additionally, large-scale renewable projects, such as solar farms, wind farms, and bioenergy plantations, can have substantial land-use impacts in Africa, potentially leading to habitat loss, biodiversity disruption, and competition with agricultural activities. Poorly managed bioenergy production, for instance, risks deforestation and ecosystem degradation. To ensure renewable energy development aligns with environmental and social needs, sustainable land-use planning and resource management are critical [199].

Additionally, Africa's role as a supplier of critical minerals raises sustainability concerns. The extraction of materials like cobalt and rare earth elements can lead to environmental degradation and social conflict [200]. Adopting responsible mining practices, advancing recycling technologies, and exploring material alternatives are necessary to minimize these impacts [199]. To ensure renewable energy adoption aligns with environmental goals, African countries must integrate LCA methods, promote sustainable land use, and invest in responsible resource management [199]. These strategies will maximize the benefits of renewable energy while minimizing adverse impacts, ensuring a sustainable energy transition for the continent.

### 4.5. To achieve the Paris Agreement's goals

Africa's vast and largely untapped renewable resources, including solar, hydroelectric, wind, and geothermal, position it uniquely to champion renewable energy adoption. Leveraging these resources could provide sustainable energy solutions, crucial for both economic growth and environmental preservation [201,202]. Renewable energy adoption in Africa is pivotal in the global effort to reduce greenhouse gas emissions, a core goal of the Paris Agreement. Although Africa's contribution to global emissions is comparatively low, prioritizing renewables allows the continent to avoid the carbon-intensive developmental paths of industrialized nations. This proactive approach not only aligns Africa with global climate mitigation efforts but also sets a precedent in low-carbon development, crucial for the health of the planet [203]. Investing in renewable energy infrastructures, such as solar and wind farms, strengthens Africa's resilience to climate change impacts like droughts and floods.

Renewable energy sources offer more stable and sustainable energy supplies, enhancing community resilience, particularly in remote and vulnerable areas [204]. The transition to renewable energy, supported by strong policy frameworks and international cooperation, is essential in realizing theParis Agreement's vision [205]. Such a transition necessitates substantial global investment and technological support to drive Africa's shift toward renewable energy, ensuring alignment with theParis Climate Agreement goals and fostering a sustainable,

**Table 10**
Estimation of The Potential Impact of Identified Risks, Considering a 2 Year, 10-Year Timeframe [195].

| 2 years | 10 years |
|---|---|
| Living expenses | Inaction on climate change mitigation |
| Weather-related catastrophes | Adaptation failure to climate change |
| Geo-economic tensions | Weather-related catastrophes |
| Inaction on climate change mitigation | Destruction of biodiversity and ecosystems |
| Social disintegration and polarization | Inaction on climate change mitigation |
| Major negative environmental occurrences | Renewable resource shortages |
| Adaptation failure to climate change | Social disintegration and polarization |
| Cybersecurity and cybercrime widespread | Cybersecurity and cybercrime are widespread |
| Renewable resource shortages | Geo-economic tensions |
| Massive Unplanned migration | Major negative environmental occurrences |

Environmental Geopolitical Societal Technological Economic low-carbon future [205]. The transition from traditional to sustainable energy sources, apart from supplying large amount of the continent's energy needs, it will help to prevent climate change and meet local energy needs and economic development [206]. Collaboration with international organizations is crucial to this shift. The African Union, UN, and different international development agencies have been encouraging Africa to boost its renewable energy capabilities [207]. Through strategic investments, international cooperation, and the development of local capacities, Africa can significantly contribute to the global transition towards more sustainable energy systems, while also achieving its own economic and social development goals [120].

### 4.6. To achieve Africa's net zero goals and ambitious Nationally Determined Contributions (NDC)

Africa's NDC calls for a shift to low-carbon energy sources, which is essential for both the region's sustainable development and achieving global climate targets. Two essential elements of this shift are the use of renewable energy sources and the decrease in greenhouse gas emissions [208]. However, implementing this change will present serious hurdles for African nations. These difficulties include the need to strike a balance between economic development and environmental preservation, energy poverty, policy execution, and financial accessibility [209]. Positive advancements have occurred despite these challenges, with nations such as Senegal advancing their National Energy Efficiency Action Plans (NEEAP) and National Renewable Energy Action Plans (NREAP) [210]. To ensure a fair transition to lower-carbon and more environmentally friendly economies, African nations must increase their investments in clean fuels, technology, and renewable energy [211]. As part of the Paris Agreement, African nations have filed their NDCs, which set forth their commitment to lowering greenhouse gas emissions and preparing for the effects of climate change [212].

A lot of African nations have set high goals to improve resilience and lower emissions intensity [213]. Kenya, for instance, has set itself an NDC that calls for a 30 % reduction in emissions by 2030, mostly from renewable energy sources [214]. Similarly, some African countries are currently pledging to meet Net Zero targets, which entail achieving carbon neutrality by matching removals and emissions of greenhouse gases [215]. As one of the continent's biggest emitters, South Africa has promised to reach net zero emissions by 2050. The nation's climate targets and policies are rated as "insufficient" by the Climate Action Tracker (CAT) [44]. The "insufficient" rating implies that South Africa's climate policies and pledges need to be significantly improved to meet the Paris Agreement's 1.5 °C temperature target [216,217]. Morocco has made several big steps toward addressing climate change, but it is still heavily reliant on coal. Morocco's climate goals and achievements continue to be ranked as "almost sufficient" by the CAT [218]. The Kenyan government's existing policies easily fulfill the unconditional emissions reduction target, but it would need to propose a more ambitious conditional aim if it is willing to meet the conditional NDC target. Kenya's endeavor to fulfill the target was recently assessed as "critically insufficient," while Gambia's conditional NDC aim versus simulated domestic pathways was downgraded from "1.5 °C compatible" to "almost sufficient" [219]. Africa's NDCs and emerging Net Zero ambitions reflect the continent's commitment to addressing climate change and renewable energy plays a central role in realizing these aspirations by reducing emissions, expanding energy access, and driving economic growth.

**Table 11**
South Africa, Morocco, Gambia, and Kenya's net-zero targets.

| Country | Net Zero Target | Overall Rating | Status Date | Ref |
|---|---|---|---|---|
| South Africa | 2050 | Insufficient | Oct-22 | [216,218] |
| Morocco | Not Specified | Almost Sufficient | Apr-23 | [218] |
| Kenya | No Target | Almost Sufficient | May-22 | [220] |
| Gambia | 2050 | Almost Sufficient | Feb-22 | [219] |

Table 11 shows the summary of South Africa, Morocco, Gambia, and Kenya's net-zero targets.

### 4.7. Socio-economic benefits of renewable energy in Africa

Renewable energy deployment in Africa offers a wide array of socio-economic benefits, contributing to sustainable development, economic growth, and social well-being [221]. The transition to renewable energy presents opportunities to address key challenges, such as energy poverty and unemployment, while fostering an environment conducive to investment and growth [222]. By providing reliable and affordable energy, renewable sources can enhance economic opportunities, create jobs, and improve living standards, particularly in rural and underserved areas [223]. For example, renewable energy projects often generate employment in construction, installation, operations, and maintenance, while supporting small and medium-sized enterprises (SMEs) [224]. This localized economic activity reduces the need for migration in search of economic opportunities and promotes socio-economic stability [152]. Additionally, the sector attracts foreign direct investment (FDI) by signaling a commitment to sustainable development, fostering economic partnerships, and diversifying Africa's economy [225]. Investments in renewable energy infrastructure also facilitate technological innovation, knowledge transfer, and skills development, further strengthening the industrial and economic fabric [226].

However, while these benefits are significant, the transition to renewable energy is not without trade-offs, particularly concerning traditional energy sectors. The growth of renewables could lead to job displacement in fossil fuel-dependent industries such as coal mining, oil extraction, and gas production, which currently employ a large workforce in some African countries [227]. For instance, nations like Nigeria, where oil contributes significantly to the economy and employment, may face challenges in reskilling workers and transitioning communities reliant on fossil fuel industries [228]. Without well-designed policies and support systems, these job losses could exacerbate social inequalities and economic insecurity [229].

Moreover, renewable energy projects, particularly large-scale solar, wind, or hydropower developments, can present localized environmental and social challenges. Land acquisition for renewable infrastructure can disrupt farming activities and displace communities, particularly in densely populated rural areas [230]. Additionally, energy transition strategies focused primarily on centralized renewable energy generation may overlook the immediate needs of fossil fuel workers and their families, creating social tensions [231].

To mitigate these trade-offs, African governments and stakeholders must adopt just transition frameworks that prioritize inclusivity and social equity. These include investing in reskilling and upskilling programs for workers transitioning from traditional energy sectors to renewables, ensuring that economic benefits are distributed equitably, and developing localized renewable energy solutions to minimize land conflicts and community displacement [232]. Collaboration with international partners can support such initiatives through technology transfer, capacity building, and financial assistance [233].

## 5. Suggestions for sustainable energy in Africa development

### 5.1. Awareness-building

Developing Africa requires a greater awareness of the realities and advantages of renewable energy technologies [234]. Misconceptions exist concerning the capabilities and limitations of renewable energy, as it is sometimes negatively viewed due to outdated information and prior restrictions. In Africa, renewable energy is frequently viewed as a costly, erratic, and time-consuming substitute for conventional energy sources [235]. The renewable energy industry has seen substantial transformation and advancement in the last ten years, characterized by the rapid implementation of increasingly efficient and economically viable technology. Growing research on markets and policy in emerging and developing nations has been published in recent years; these studies have yielded insightful analysis, best practices, and technical breakthroughs that have increased productivity [236]. The energy sector is undergoing fast changes driven by the imperative of addressing climate change, which is accelerating the global energy revolution. In an era of dynamic worldwide transformations, it is imperative to establish accurate assessments of the true costs, performance, and dependability characteristics of various technologies.

### 5.2. Policy and regulation frameworks

The government's allocation of limited resources often leads to the prioritization of other sectors compared with renewable energy, resulting in a lack of political commitment and consistency in policies. The article previously addressed several obstacles that hinder Africa's adoption of renewable energy. Governments, businesses, and international development partners must place a high priority on renewable energy and make it the top priority on their agendas to successfully remove these barriers [171]. By involving all parties and utilizing their skills and experience, those challenges can be successfully addressed [237]. Significant alterations have been made to the legal and regulatory structures of numerous African nations. Two well-known programs, the Continental Power System Masterplan (CMP) with the African Single Electricity Market (AfSEM), are designed to assist the continent's power industry and foster energy collaboration between Europe and Africa [94]. However, ensuring the success of these programs requires policies tailored to the unique energy needs and conditions of urban and rural areas. Urban energy strategies should prioritize grid modernization, efficient land use planning, and incentivizing private-sector investment, while rural strategies must focus on scaling decentralized systems, building local capacity, and integrating renewable energy solutions with community development initiatives [97]. These tailored approaches are essential for advancing sustainable energy transitions in Africa, aligning with both regional development goals and global climate objectives.

In addition to renewable energy, the management of other natural resources, such as minerals critical for renewable technologies (e.g., lithium, cobalt, and nickel), requires targeted and comprehensive policy interventions [238]. Many African countries possess significant reserves of these minerals, yet the absence of robust governance frameworks often leads to inefficiencies, environmental degradation, and social conflicts [239]. To address these issues, policies must prioritize sustainable extraction practices while ensuring that local communities benefit equitably from resource revenues. This can be achieved by promoting transparency in mining operations, equitable distribution of revenues, and strict adherence to environmental standards. Furthermore, fostering value addition through local processing and manufacturing is essential for creating jobs and reducing dependence on raw material exports. Incentives such as tax breaks or subsidies for processing facilities can play a significant role in achieving this goal [240].

International collaboration is also crucial to establishing fair trade practices and aligning resource governance with global sustainability standards. Integrating resource governance into national development plans is vital for aligning these efforts with broader objectives, such as achieving the SDGs and fulfilling commitments under the Paris Agreement [241]. By adopting a holistic and inclusive approach to policy-making, African nations can effectively harness their natural resources, including renewable energy and critical minerals, to drive sustainable development, enhance energy security, and facilitate economic transformation [242].

### 5.3. Enhancing the investment climate and mitigating risks

More capital must be allocated to renewable energy in Africa than the 1.6 % cap now in place. The application of project risk reduction techniques is crucial to promoting the expansion of renewable energy investments in Africa [243]. For most African republics, obtaining financial resources remains a formidable challenge. Capital expenses might differ by up to seven times between a location and the US or Europe [66]. It is very important to spend more than Africa's current limit of 0.6 % on renewable energy. To help the growth of renewable energy investments in Africa, it is important to use project risk reduction methods [244]. Gaining access to financial resources is still a difficult task for most African states. Investment expenses can be as much as sevenfold higher in some locations than they are in the US or Europe. Africa needs to put a lot of money into renewable energy sources on a scale that has never been seen before if it wants to reach its goals for sustainable growth. Securing enough funds is a big problem in this situation [11]. To accomplish SDG 7 goals, Africa must invest 190 billion USD a year in energy between 2026 and 2030, with 70 % allocated to clean energy as shown in Fig. 10.

## 6. Limitation of study, future outlook, and conclusion

### 6.1. Limitations of the study

This study provides a comprehensive analysis of the renewable energy market in Africa, offering valuable insights into the role of renewable energy and critical resources in Africa's energy transition. However, there are several limitations that warrant acknowledgment. First, the study focuses predominantly on solar, wind, hydropower, and biomass as renewable energy sources, while other resources such as tidal and wave energy, green hydrogen, and advanced bioenergy (such as biogas) are not explored in depth. This may affect the generalizability of some findings to other renewable resources. Additionally, the analysis of critical minerals essential for renewable energy technologies, such as lithium, cobalt, and nickel, is constrained by limited data on the socio-environmental impacts of their extraction and usage in Africa. Future research should delve deeper into the governance frameworks and local implications of mineral resource management to provide a more holistic view.

### 6.2. Future outlook

Future research should explore underrepresented renewable energy sources in Africa, such as tidal and wave energy, green hydrogen, and advanced bioenergy (biogas), alongside solar, wind, hydropower, and biomass. This will ensure a broader understanding of the continent's full energy potential. Addressing infrastructure challenges in transmission, storage, and distribution is crucial. Advanced technologies like AI-driven energy management, machine learning, and predictive maintenance can enhance grid performance and facilitate the seamless integration of diverse renewable energy sources. Research must assess the environmental impacts of renewable energy deployment, including land use and ecosystem effects. Tools like Integrated Assessment Models (IAMs) can evaluate the long-term socio-environmental and economic impacts, ensuring alignment with sustainable development goals. Effective financing strategies, including blended finance, green bonds, and public-private partnerships, are needed to scale renewable projects in Africa. Additionally, expanding regional energy markets through super grids and cross-border interconnectors can enhance energy trade and resource utilization.

The linkage between FDI and renewable energy in Africa is a critical area of study. FDI plays a crucial role in the development of renewable energy infrastructure, bringing in necessary capital, technology, and expertise. Research should focus on how investment patterns influence RE adoption, considering regulatory environments, energy policies, and geopolitical stability. Understanding the economic impacts of FDI on renewable energy projects can provide insights into market dynamics, employment creation, and industrial growth in Africa. Additionally, sustainable extraction and governance of critical minerals such as

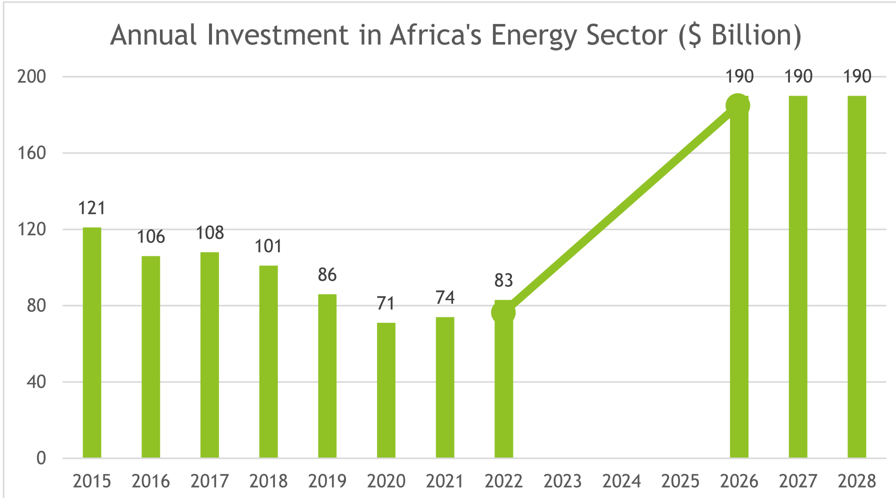


**Fig. 10.** The annual investment deficit in Africa's energy sector [245].

cobalt, nickel, and rare earth elements are essential for the advancement of renewable energy technologies. Africa holds significant reserves of these minerals, making it imperative to ensure responsible mining practices and equitable value distribution. Machine learning and econometric models can help assess market dynamics and environmental impacts, promoting a balanced approach to mineral resource management. Policymakers must consider global best practices to ensure resource sustainability while maximizing economic benefits.

### *6.3. Conclusion*

This study highlights Africa's immense potential to address energy challenges through renewable sources like solar, wind, and geothermal. However, realizing this potential requires concerted efforts to overcome barriers such as inadequate infrastructure, financial constraints, and limited regional cooperation. Policymakers must prioritize creating regulatory frameworks and financial incentives to attract investment, while regional energy integration through initiatives like the Southern African Power Pool will optimize resource utilization and enhance trade. Technological advancements, such as AI-driven energy management systems offer critical solutions for improving grid efficiency and integrating diverse renewable sources.

It is recommended that stakeholders focus on several key actions. First, addressing the infrastructure challenges of energy transmission and storage is paramount. Adopting machine learning and predictive maintenance technologies can improve grid performance and enable smoother renewable energy integration. Financial models tailored to Africa's unique economic landscape, such as green bonds and public-private partnerships, are essential to scaling renewable projects. Additionally, expanding regional energy markets and creating super grids will facilitate greater cross-border energy trade. For the long-term sustainability of the sector, the governance of critical minerals like cobalt and nickel, essential for renewable energy technologies, must be strengthened through transparent, sustainable extraction practices. By implementing these strategies, stakeholders can unlock Africa's renewable energy potential, ensuring energy security, environmental sustainability, and socio-economic growth across the continent.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

Data will be made available on request.

## References


[1] D.W.R. Dr Fatih Birol, A New Energy Pact for Africa, Project Syndicate, IEA, Jul. 13, 2023 [Online]. Available: https://www.iea.org/commentaries/a-new-energy-pact-for-africa. (Accessed 5 October 2023).

[2] Global LNG Hub, The role of natural gas in powering Africa's future [Online]. Available: https://www.gecf.org/events/expert-commentary-the-role-of-natural-gas-in-powering-africa, 2023. (Accessed 30 October 2023).

[3] Statista Research Department, Forecast of the total population of Africa 2020-2050 [Online]. Available: https://www.statista.com/statistics/1224205/forecast-of-the-total-population-of-africa/, Apr. 2023. (Accessed 5 October 2023).

[4] D. Ramalope, et al., Renewable energy transition in sub-Saharan Africa [Online]. Available: www.climateanalytics.org, 2022.

[5] Statista Research Department, Number of people without access to electricity worldwide in selected years from 2000 to 2023, by region [Online]. Available: https://www.statista.com/statistics/829803/number-of-people-without-access-to-electricity-by-region/, Sep. 2023. (Accessed 5 October 2023).

[6] World Health Organization and others, Tracking SDG 7: the Energy Progress Report 2021, 2021. Washington DC.

[7] The World Bank, Solar mini grids could sustainably power 380 million people in Africa by 2030 – if action is taken now [Online]. Available: https://www.worldbank.org/en/news/press-release/2023/02/26/solar-mini-grids-could-sustainably-power-380-million-people-in-afe-africa-by-2030-if-action-is-taken-now, Feb. 26, 2023. (Accessed 15 October 2023).

[8] N. Li, D. Agene, L. Gu, R. Osabohien, A.H. Jaaffar, Promoting clean energy adoption for enhanced food security in Africa, Front. Sustain. Food Syst. 8 (Jan) (2024), https://doi.org/10.3389/fsufs.2024.1269160.

[9] IEA, Data and statistics [Online]. Available: https://www.iea.org/data-and-statistics/data-tables?country=WORLD, 2021. (Accessed 8 April 2024).

[10] I.D. Ibrahim, et al., A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study, Energy Strategy Rev. 38 (Nov. 2021) 100740, https://doi.org/10.1016/j.esr.2021.100740.

[11] T. Aryn Baker, Financing Clean Energy in Africa, OECD, 2023, https://doi.org/10.1787/0d5a2eee-en.

[12] K. Shulla, et al., Effects of COVID-19 on the sustainable development goals (SDGs), Discov. Sustain. 2 (1) (Dec. 2021) 15, https://doi.org/10.1007/s43621-021-00026-x.

[13] Nopenyo Dabla, Sustainable energy for Africa (SE4A 2021), in: Georges VAN GOETHEM, M.A.I.R.Y. Bernard, Thierry D'ALMEIDA (Eds.), *Renewable Energy As an Enabler for Socio-Economic Development in Africa*, Norbert HOUNKONNOU, Nov. 2021. Accessed: Oct. 05, 2023. [Online]. Available: https://events.spacepole.be/event/91/attachments/516/1334/SE4A_2021_programme_v9.pdf.

[14] Le Groupe d'études géopolitiques, Africa has the most to gain from clean energy transitions [Online]. Available: https://geopolitique.eu/en/2022/06/29/africa-has-the-most-to-gain-from-clean-energy-transitions/, 2022. (Accessed 5 November 2023).

[15] World Health Organization, WHO Publishes New Global Data on the Use of Clean and Polluting Fuels for Cooking by Fuel Type, Jan. 20, 2022 [Online]. Available: https://www.who.int/news/item/20-01-2022-who-publishes-new-global-data-on-the-use-of-clean-and-polluting-fuels-for-cooking-by-fuel-type. (Accessed 5 October 2023).

[16] C.J. Schuster-Wallace, A.Z. Qadir M., F. Renaud, S.K. Dickin, Putting water and energy at the heart of sustainable development. CANADA, United Nations University, Hamilton, 2022 [Online]. Available: https://inweh.unu.edu/. (Accessed 5 October 2023).

[17] A.S. Oyewo, S. Sterl, S. Khalili, C. Breyer, Highly renewable energy systems in Africa: rationale, research, and recommendations, Joule 7 (7) (Jul. 2023) 1437–1470, https://doi.org/10.1016/j.joule.2023.06.004.

[18] Darlington Eze Ekechukwu, Peter Simpa, Trends, insights, and future prospects of renewable energy integration within the oil and gas sector operations, World Int. J. Adv. Sci. Eng. Technol. 12 (1) (May 2024) 152–167, https://doi.org/10.30574/wjaets.2024.12.1.0207.

[19] M. Farghali, et al., Strategies to save energy in the context of the energy crisis: a review, Environ. Chem. Lett. 21 (4) (2023) 2003–2039, https://doi.org/10.1007/s10311-023-01591-5.

[20] M.B. Bouraima, B. Ibrahim, Y. Qiu, L.J. Muhammad, M. Radovanović, Assessment of solar energy technologies in meeting the 2030 agenda and sustainable development goals under an interval-valued fermatean fuzzy environment, J. Oper. Intell. 2 (1) (Jan. 2024) 114–128, https://doi.org/10.31181/jopi21202412.

[21] H. Kumba, O.A. Olanrewaju, Towards sustainable development: analyzing the viability and integration of renewable energy solutions in South Africa'—a review, Energies (Basel) 17 (6) (Mar. 2024) 1418, https://doi.org/10.3390/en17061418.

[22] M.T. Saleh, Hydrogen in Africa: navigating the continent's unique energy transition landscape and unsustainable energy supply backbone, in: Africa International Conference on Clean Energy and Energy Storage, Trans Tech Publications Ltd., Mar. 2024, pp. 3–14, https://doi.org/10.4028/p-rM7YHe.

[23] Olushola Babatunde Ayorinde, Emmanuel Augustine Etukudoh, Zamathula Queen Sikhakhane Nwokediegwu, Kenneth Ifeanyi Ibekwe, Aniekan Akpan Umoh, Ahmad Hamdan, Renewable energy projects in Africa: a review of climate finance strategies, Inter. J. Sci. Res. Archive 11 (1) (Jan. 2024) 923–932, https://doi.org/10.30574/ijsra.2024.11.1.0170.

[24] Onyinyechukwu Chidolue, Adetomilola Victoria Fafure, Valentine Ikenna Illojianya, Bright Ngozichukwu, Cosmas Dominic Daudu, Kenneth Ifeanyi Ibekwe, Integration of renewable energy in industrial operations: experiences from Canada, USA, and Africa, GSC Adv. Res. Reviews 18 (1) (Jan. 2024) 213–221, https://doi.org/10.30574/gscarr.2024.18.1.0014.

[25] R. Ngcobo, M.C. De Wet, The impact of financial development and economic growth on renewable energy supply in South Africa, Sustainability 16 (6) (Mar. 2024) 2533, https://doi.org/10.3390/su16062533.

[26] O. Awogbemi, D.V. Von Kallon, Towards the development of underutilized renewable energy resources in achieving carbon neutrality, Fuel Communications 17 (Dec. 2023) 100099, https://doi.org/10.1016/j.jfueco.2023.100099.

[27] RES4 Africa Foundation, AFRICA'S ENERGY FUTURE IS RENEWABLE, Jun. 2023.

[28] A. Benkenstein, R. Chevallier, Partnership for a green transition and energy access: strategic priorities for Africa and Europe, S. Afr. Institut. Int. Aff. (2020), 10.500.12592/1w0917.

[29] Saifaddin Galal, Solar energy capacity in Algeria 2012-2022 [Online]. Available: https://www.statista.com/statistics/1370923/solar-energy-capacity-in-algeria/, Jun. 2023. (Accessed 6 November 2023).

[30] A. Laaroussi, O. Laaroussi, A. Bouayad, Environmental impact study of the NOOR 1 solar project on the Southern Region of Morocco, Renew. Energy Environ. Sustain. 8 (Jul. 2023) 9, https://doi.org/10.1051/rees/2023007. Renew. Energy Environ. Sustain.

[31] N.E. Benti, T.A. Woldegiyorgis, C.A. Geffe, G.S. Gurmesa, M.D. Chaka, Y. S. Mekonnen, Overview of geothermal resources utilization in Ethiopia: potentials, opportunities, and challenges, Sci Afr 19 (Mar. 2023) e01562, https://doi.org/10.1016/j.sciaf.2023.e01562.

[32] N.E. Benti, et al., The current status, challenges and prospects of using biomass energy in Ethiopia, Biotechnol. Biofuels 14 (1) (Oct. 2021) 209, https://doi.org/10.1186/s13068-021-02060-3.

[33] S. Elbarbary, M. Abdel Zaher, H. Saibi, A.-R. Fowler, K. Saibi, Geothermal renewable energy prospects of the African continent using GIS, Geoth. Energy 10 (1) (Dec. 2022) 8, https://doi.org/10.1186/s40517-022-00219-1.

[34] Natalie Cowling, Installed capacity of wind power in Kenya 2017-2022 [Online]. Available: https://www.statista.com/statistics/1240882/installed-capacity-of-wind-power-in-kenya/, Sep. 2023. (Accessed 5 November 2023).

[35] Andritz, Mozambique - power-up growth [Online]. Available: https://www.andritz.com/hydro-en/hydronews/hydropower-africa/mozambique. (Accessed 6 November 2023).

[36] Saifaddin Galal, Total wind energy capacity in Egypt 2012-2022 [Online]. Available: https://www.statista.com/statistics/1215513/egypt-total-wind-energy-capacity, Jun. 2023. (Accessed 5 November 2023).

[37] Ministry of Energy Development, Overview of hydropower in Kenya [Online]. Available: https://www.energy.go.ke/small-hydropower-development-keny. (Accessed 6 November 2023).

[38] Mordor Intelligence, Ghana solar energy market size & share analysis - growth trends & forecasts (2023 - 2028) [Online]. Available: https://www.mordorintelligence.com/industry-reports/ghana-solar-energy-market, 2023. (Accessed 6 November 2023).

[39] State Department Energy, Bioenergy [Online]. Available: https://www.energy.go.ke/biogas, 2023. (Accessed 6 November 2023).

[40] International Trade Administration, Morocco - energy [Online]. Available: https://www.trade.gov/country-commercial-guides/morocco-energy. (Accessed 6 November 2023).

[41] Carlo Cariaga, Tanzania Government Targets 200 MW Geothermal Capacity by 2025 [Online]. Available:, Think Geoenergy, Dec. 04, 2021 https://www.thinkgeoenergy.com/tanzania-government-targets-200-mw-geothermal-capacity-by-2025/. (Accessed 4 November 2023).

[42] International Trade Administration, Electricity. Power systems and renewable energy [Online]. Available: https://www.trade.gov/country-commercial-guides/kenya-energy-electrical-power-systems. (Accessed 6 November 2023).

[43] S.E. A, M.F. H, T.M. H, Maryam K. Abdelrazik, Climate action: prospects of solar energy in Africa, Energy Rep. 8 (Nov. 2022).

[44] M.K. Abdelrazik, S.E. Abdelaziz, M.F. Hassan, T.M. Hatem, Climate action: prospects of solar energy in Africa, Energy Rep. 8 (Nov. 2022) 11363–11377, https://doi.org/10.1016/j.egyr.2022.08.252.

[45] Sustainable Review, Part one: the green sahara, in: When the Sahara Was Green, Princeton University Press, 2021, pp. 7–58, https://doi.org/10.1515/9780691228891-005.

[46] A.A. Adenle, Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals, Energy Policy 137 (Feb. 2020) 111180, https://doi.org/10.1016/j.enpol.2019.111180.

[47] T.R. Ayodele, J.L. Munda, The potential role of green hydrogen production in the South Africa energy mix, J. Renew. Sustain. Energy 11 (4) (Jul. 2019) 044301, https://doi.org/10.1063/1.5089958.

[48] AJOT, "Africa's renewable energy capacity is set for consecutive years of growth, exceeding 50 GW in 2025," *AJOT*, 2020 [Online]. Available: https://www.ajot.com/news/africas-renewable-energy-capacity-is-set-for-consecutive-years-of-growth-exceeding-50-gw-in-2025. (Accessed 6 January 2025).

[49] G. Falchetta, D.E.H.J. Gernaat, J. Hunt, S. Sterl, Hydropower dependency and climate change in sub-Saharan Africa: a nexus framework and evidence-based review, J. Clean. Prod. 231 (Sep. 2019) 1399–1417, https://doi.org/10.1016/j.jclepro.2019.05.263.

[50] A. Adeleke, F. Inzoli, E. Colombo, Renewable energy development in Africa: lessons and policy recommendations from South Africa, Egypt, and Nigeria, in: Renewable Energy for Sustainable Growth Assessment, Wiley, 2022, pp. 263–304, https://doi.org/10.1002/9781119785460.ch10.

[51] P. Elsner, Continental-scale assessment of the African offshore wind energy potential: spatial analysis of an under-appreciated renewable energy resource, Renew. Sustain. Energy Rev. 104 (Apr. 2019) 394–407, https://doi.org/10.1016/j.rser.2019.01.034.

[52] R. Davy, N. Gnatiuk, L. Pettersson, L. Bobylev, Climate change impacts on wind energy potential in the European domain with a focus on the Black Sea, Renew. Sustain. Energy Rev. 81 (Jan. 2018) 1652–1659, https://doi.org/10.1016/j.rser.2017.05.253.

[53] M.A. Ozgur, R. Kose, Assessment of the wind energy potential of kutahya, Turkey, Energy Explor. Exploit. 24 (4) (Aug. 2006) 331–347, https://doi.org/10.1260/014459806779398820.

[54] D. Mikicic, B. Radicevic, Z. Djurisic, Wind energy potential in the world and in Serbia and Montenegro, Facta Univ. – Ser. Electron. Energetics 19 (1) (2006) 47–61, https://doi.org/10.2298/FUEE0601047M.

[55] Z. Zeng, et al., A reversal in global terrestrial stilling and its implications for wind energy production, Nat. Clim. Change 9 (12) (Dec. 2019) 979–985, https://doi.org/10.1038/s41558-019-0622-6.

[56] K. Adeyeye, N. Ijumba, J. Colton, A preliminary feasibility study on wind resource and assessment of a novel low speed wind turbine for application in Africa, Energy Eng. J. Assoc. Energy Eng. 119 (3) (2022) 997–1015, https://doi.org/10.32604/ee.2022.018677.

[57] D. Pullinger, A. Ali, M. Zhang, N. Hill, T. Crutchley, Improving accuracy of wind resource assessment through feedback loops of operational performance data: a South African case study, J. Energy South Afr. 30 (3) (Sep. 2019) 1–10, https://doi.org/10.17159/2413-3051/2019/v30i3a5669.

[58] K. Umoh, M. Lemon, Drivers for and barriers to the take up of floating offshore wind technology: a comparison of scotland and South Africa, Energies (Basel) 13 (21) (Oct. 2020) 5618, https://doi.org/10.3390/en13215618.

[59] G. Rae, G. Erfort, Offshore wind energy – South Africa's untapped resource, J. Energy South Afr. 31 (4) (Nov. 2020) 26–42, https://doi.org/10.17159/2413-3051/2020/v31i4a7940.

[60] W. Sawadogo, et al., Current and future potential of solar and wind energy over Africa using the RegCM4 CORDEX-CORE ensemble, Clim. Dyn. 57 (5–6) (Sep. 2021) 1647–1672, https://doi.org/10.1007/s00382-020-05377-1.

[61] Goodrich Grace, Top 10: wind farms in Africa, Energy Capital & Power (2021) [Online]. Available: https://energycapitalpower.com/top-10-wind-farms-in-africa. (Accessed 20 December 2023).

[62] R.A.H.U.L. Rao, African Hydropower Confronts Cheap Solar and Wind, Sep. 2023.

[63] World Economic Forum, IEA: more than a third of the world's electricity will come from renewables in 2025 [Online]. Available: https://www.weforum.org/agenda/2023/03/electricity-generation-renewables-power-iea/#:~:text=Renewable%20energy%20will%20produce%2035,2025%3A%20IEA%20%7C%20World%20Economic%20Forum, Mar. 2023. (Accessed 29 October 2023).

[64] IRENA, Renew. Energy Statistics (2022). Abu Dhabi, Mar. 2023, https://www.irena.org/Statistics/Download-Data. (Accessed 5 October 2023).
[65] S. Jain, Global potential of biogas [Online]. Available: https://www.worldbiogasassociation.org/wp-content/uploads/2019/07/WBA-globalreport-56ppa4_digital.pdf, Mar. 2023. (Accessed 28 October 2023).
[66] M.M. Ali, M. Ndongo, B. Bilal, K. Yetilmezsoy, I. Youm, M. Bahramian, Mapping of biogas production potential from livestock manures and slaughterhouse waste: a case study for African countries, J. Clean. Prod. 256 (120499) (May 2020) 120499, https://doi.org/10.1016/j.jclepro.2020.120499.
[67] V. Tumwesige, D. Fulford, G.C. Davidson, Biogas appliances in sub-sahara Africa, Biomass Bioenergy 70 (Nov. 2014) 40–50, https://doi.org/10.1016/j.biombioe.2014.02.017.
[68] Lucía Fernández, Biogas energy capacity worldwide from 2009 to 2022(in megawatts) [Online]. Available: https://www.statista.com/statistics/476338/global-capacity-of-total-bioenergy/, Jul. 2023. (Accessed 30 October 2023).
[69] A. A. A. A. O. O. S. A., F.O.E. Joan Nyika, The potential of biomass in Africa and the debate on its carbon neutrality [Online]. Available: : https://www.researchgate.net/publication/344638846, Oct. 2020. (Accessed 5 November 2023).
[70] Africa Region, Forests, Trees, and Woodlands in AFRICA - an Action Plan for World Bank Engagement, 2022.
[71] S. Dasappa, Potential of biomass energy for electricity generation in sub-Saharan Africa, Energy for Sustain. Dev. 15 (3) (Sep. 2011) 203–213, https://doi.org/10.1016/j.esd.2011.07.006.
[72] A. Santoro, M. Venturi, R. Bertani, M. Agnoletti, A review of the role of forests and agroforestry systems in the FAO globally important agricultural heritage systems (GIAHS) Programme, Forests 11 (8) (Aug. 2020) 860, https://doi.org/10.3390/f11080860.
[73] GEP, Tapping geothermal energy for power generation in the MENA region [Online]. Available: https://www.gep.com/blog/mind/tapping-geothermal-energy-for-power-generation-in-mena-region, Dec. 2024. (Accessed 7 January 2025).
[74] S. Elbarbary, M. Abdel Zaher, H. Saibi, A.R. Fowler, K. Saibi, Geothermal renewable energy prospects of the African continent using GIS, Geoth. Energy 10 (1) (Dec. 2022), https://doi.org/10.1186/s40517-022-00219-1.
[75] Ministry of Energy and Petrtoleum, GREEN HYDROGEN STRATEGY AND ROADMAP FOR KENYA, 2023.
[76] International Renewable Energy Agency, Geothermal [Online]. Available: https://www.irena.org/Energy-Transition/Technology/Geothermal-energy, 2023. (Accessed 19 March 2024).
[77] O. Bamisile, et al., Geothermal energy prospect for decarbonization, EWF nexus and energy poverty mitigation in East Africa; the role of hydrogen production, Energy Strategy Rev. 49 (Sep) (2023), https://doi.org/10.1016/j.esr.2023.101157.
[78] iAfrica, "Africa's Geothermal Potential Could Power the Continent by 2050" iAfrica. Accessed: January. 7, 2025. [Online]. Available: https://iafrica.com/africas-geothermal-potential-could-power-the-continent-by-2050/.
[79] J. Langer, K. Blok, The global techno-economic potential of floating, closed-cycle ocean thermal energy conversion, J. Ocean Eng. Mar. Energy 10 (1) (Feb. 2024) 85–103, https://doi.org/10.1007/s40722-023-00301-1.
[80] Africa Union "AGENDA 2063 Report of the Commission on the African Union Agenda 2063 The Africa We Want in 2063." [Online]. Available: www.au.int.
[81] B. Lu, Y. Liu, X. Zhai, L. Zhang, Y. Chen, Design and experimental study of 50 kW Ocean Thermal energy conversion test platform based on organic rankine cycle, J. Mar. Sci. Eng. 12 (3) (Mar. 2024) 463, https://doi.org/10.3390/jmse12030463.
[82] Y. Zhang, et al., Formation of LiF surface layer during direct fluorination of high-capacity Co-free disordered rocksalt cathodes, ACS Appl. Mater. Interfaces 13 (32) (Aug. 2021) 38221–38228, https://doi.org/10.1021/acsami.1c07882.
[83] L. Kavanagh, J. Keohane, G. Garcia Cabellos, A. Lloyd, J. Cleary, Global lithium sources—industrial use and future in the electric vehicle industry: a review, Resources 7 (3) (Sep. 2018) 57, https://doi.org/10.3390/resources7030057.
[84] AfDB, Rich in green minerals, African countries eye booming electric vehicle and clean energy market worth trillions of dollars [Online]. Available: https://www.afdb.org/en/news-and-events/rich-green-minerals-african-countries-eye-booming-electric-vehicle-and-clean-energy-market-worth-trillions-dollars-65241, Oct. 2023.
[85] Y.A. Obafemi, Non-oil sectors, economic diversification and growth in Nigeria: further empirical evidence, Stud. Bus. Econ. 17 (1) (Apr. 2022) 290–311, https://doi.org/10.2478/sbe-2022-0019.
[86] C.A. Chapman, et al., The future of sub-Saharan Africa's biodiversity in the face of climate and societal change, Front Ecol. Evol. 10 (Aug) (2022), https://doi.org/10.3389/fevo.2022.790552.
[87] A.O. Ali, A.S. Morshedy, A.A. El-Zahhar, M.M. Alghamdi, A.M.A. El Naggar, African continent: rich land of minerals and energy sources, Inorg. Chem. Commun. 169 (Nov. 2024) 113123, https://doi.org/10.1016/j.inoche.2024.113123.
[88] Africa's critical minerals Africa at the heart of a low-carbon future".
[89] J. Boafo, J. Obodai, E. Stemn, P.N. Nkrumah, The race for critical minerals in Africa: a blessing or another resource curse? Resour. Policy 93 (Jun. 2024) 105046 https://doi.org/10.1016/j.resourpol.2024.105046.
[90] Y. Zhou, Y. Liu, J. Niu, Role of mineral-based industrialization in promoting economic growth: implications for achieving environmental sustainability and social equity, Resour. Policy 88 (Jan. 2024) 104396, https://doi.org/10.1016/j.resourpol.2023.104396.
[91] Charles Asiegbu "Lithium could fuel the next conflict in Nigeria," London School of Economics. Accessed: December. 8, 2023. [Online]. Available: https://blogs.lse.ac.uk/africaatlse/2023/08/24/lithium-could-fuel-the-next-conflict-in-nigeria/.
[92] IEA, Trends in Electric Vehicle Batteries – Global EV Outlook 2024, 2024.
[93] M. Agoundedemba, C.K. Kim, H.-G. Kim, Energy status in Africa: challenges, progress and sustainable pathways, Energies (Basel) 16 (23) (Nov. 2023) 7708, https://doi.org/10.3390/en16237708.
[94] IEA, Africa energy outlook 2022 [Online]. Available: https://www.iea.org/reports/africa-energy-outlook-2022, 2022. (Accessed 29 October 2023).
[95] A.M. Fagge, Renewable energy and the state of environmental quality in Nigeria, Gujeds (2023), https://doi.org/10.57233/gujeds.v3i1.15.
[96] S. Diallo, Effect of renewable energy consumption on environmental quality in sub-Saharan African countries: evidence from defactored instrumental variables method, Manag. Environ. Qual. Int. J. 35 (4) (May 2024) 839–857, https://doi.org/10.1108/MEQ-09-2023-0326.
[97] I. Renewable Energy Agency, The energy transition in Africa: Opportunities for international collaboration with a focus on the G7 [Online]. Available: www.irena.org, 2024.
[98] S. Pachauri, O. Coldrey, G. Falchetta, S. Pelz, Innovation in distributed energy services for sustainable development: case studies from sub-Saharan Africa, Environ. Res. Lett. 19 (11) (Nov. 2024) 114090, https://doi.org/10.1088/1748-9326/ad8460.
[99] M.C. Ezeh, T.H. Fidel-Anekwe, P.B. Ikpabi, Evaluating the potential of renewable energy to address energy accessibility, affordability, and sustainability challenges in Africa, in: *SPE Nigeria Annual International Conference And Exhibition*, SPE, Jul. 2023, https://doi.org/10.2118/217214-MS.
[100] CDKN Global, Economic recovery from Covid-19: prospects for sub-Saharan Africa [Online]. Available: https://cdkn.org/story/economic-recovery-covid-19-prospects-sub-saharan-africa, Feb. 01, 2022. (Accessed 5 November 2023).
[101] S.C. Nwokolo, R. Singh, S. Khan, A. Kumar, S. Luthra, Influencing the Scale of Africa's Energy Trans. (2023) 75–91, https://doi.org/10.1007/978-3-031-44514-9_4.
[102] S.C. Nwokolo, R. Singh, S. Khan, A. Kumar, S. Luthra, Influencing the scale of Africa's energy transition, in: Africa's Path to Net-Zero, 2023, pp. 75–91, https://doi.org/10.1007/978-3-031-44514-9_4.
[103] S. Nwokolo, E. Eyime, A. Obiwulu, J. Ogbulezie, Exploring cutting-edge approaches to reduce Africa's carbon footprint through innovative technology dissemination, Trends Renew. Energy 10 (1) (2024) 1–29, https://doi.org/10.17737/tre.2024.10.1.00163.
[104] S.C. Nwokolo, R. Singh, S. Khan, A. Kumar, S. Luthra, Remedies to the Challenges of Renewable Energy Deployment in Africa (2023) 59–74, https://doi.org/10.1007/978-3-031-44514-9_3.
[105] Shubhendra Anand Source: https://www.marketresearchfuture.com/news/africa-receives-only-2-percent-of-clean-energy-investment-funds-2024, "Africa Receives only 2 Percent of Clean Energy Investment Funds 2024 Source: https://www.marketresearchfuture.com/news/africa-receives-only-2-percent-of-clean-energy-investment-funds-2024," market research future, Sep. 2024.
[106] A.A. Lawrence, Transition from Fossil Fuel to Clean Energy: A Must Achievable Project in Sub-saharan Africa, Shodh Sari-An International Multidisciplinary Journal, Apr. 2023, pp. 41–49, https://doi.org/10.59231/SARI7573.
[107] J. Hou, W. Bai, D. Sha, Does the digital economy successfully facilitate carbon emission reduction in China? Green technology innovation perspective, Sci. Technol. Soc. 28 (4) (Dec. 2023) 535–560, https://doi.org/10.1177/09717218231161235.
[108] P. Tamasiga, M. Molala, M. Bakwena, H. Nkoutchou, H. Onyeaka, Is Africa left behind in the global climate finance architecture: redefining climate vulnerability and revamping the climate finance landscape—a comprehensive review, Sustainability 15 (17) (Aug. 2023) 13036, https://doi.org/10.3390/su151713036.
[109] Olushola Babatunde Ayorinde, Emmanuel Augustine Etukudoh, Zamathula Queen Sikhakhane Nwokediegwu, Kenneth Ifeanyi Ibekwe, Aniekan Akpan Umoh, Ahmad Hamdan, Renewable energy projects in Africa: a review of climate finance strategies, Inter. J. Sci. Res. Archive 11 (1) (Jan. 2024) 923–932, https://doi.org/10.30574/ijsra.2024.11.1.0170.
[110] Africa's Energy Future Is Renewable Its Sustainable Economic Development Depends on It".
[111] V.R. Nalule, D.S. Olawuyi, T.L. Muinzer, The role of African extractive industries in the global energy transition: an analysis of barriers and strategies, Extr. Ind. Soc. 19 (Sep) (2024), https://doi.org/10.1016/j.exis.2024.101513.
[112] The Renewable Energy Transition in Africa".
[113] V. Karbassi, P.A. Trotter, G. Walther, Diversifying the African energy system: economic versus equitable allocation of renewable electricity and e-fuel production, Appl. Energy 350 (Nov. 2023) 121751, https://doi.org/10.1016/j.apenergy.2023.121751.
[114] Kan, L. Reichenberg, F. Hedenus, D.D. Xiao-Tian, Global renewable LCOE – including socio-economic factors in assessments of resource potential (Feb. 2022).
[115] Rajesh Palanisamy, Dataset Data Source Related Posts Energy Energy Dec 15, 2024 What's the Average Cost of 1 kWh Electricity Around the World, Voroni, Dec. 2024.
[116] Q. Hassan, et al., The renewable energy role in the global energy Transformations, Renew. Energy Focus 48 (Mar. 2024) 100545, https://doi.org/10.1016/j.ref.2024.100545.
[117] Akinwale Ishola, Global renewable energy transition in fossil fuel dependent regions, World J. Adv. Res. Rev. 24 (1) (Oct. 2024) 1373–1380, https://doi.org/10.30574/wjarr.2024.24.1.3046.
[118] M. Byaro, P. Dimoso, A. Rwezaula, Are clean energy technologies a panacea for environmental sustainability in sub-Saharan African countries? (2023), https://doi.org/10.21203/rs.3.rs-2650072/v1.

[119] Saifaddin Galal, Final energy consumption in Africa 2020, by sector [Online]. Available: https://www.statista.com/statistics/1285183/final-energy-consumption-in-africa-by-sector/, Sep. 2023. (Accessed 13 November 2023).
[120] IRENA, The renewable energy transition in Africa: powering access, resilience and prosperity [Online]. Available: https://www.irena.org/publications/2021/March/The-Renewable-Energy-Transition-in-Africa, Sep. 2020. (Accessed 5 November 2023).
[121] S.S. Fatih Birol, Francesco La Camera, Demetrios Papathanasiou, Maria Neira, Gabriela Elizondo Azuela, Minoru Takada, Tracking SDG7: the Energy Progress Report 2023, Jun. 2023. Washington, http://trackingSDG7.esmap.org. (Accessed 15 October 2023).
[122] E. Kanzari, G. fazio, S. Fricano, The Energy Transition of African Countries: A Cluster Analysis, 2024, https://doi.org/10.2139/ssrn.4816701.
[123] World Bank, World Bank open data [Online]. Available: https://data.worldbank.org/, 2024. (Accessed 25 October 2024).
[124] ENERGY: Africa, Africa research bulletin: economic, Financial and Technical Series 60 (1) (Mar. 2023), https://doi.org/10.1111/j.1467-6346.2023.10995.x.
[125] B.J. Kanyama, S.M. Seeletse, The effects of power usage on five power modes in South Africa using multivariate techniques, Am. J. Appl. Sci. 15 (1) (Jan. 2018) 22–29, https://doi.org/10.3844/ajassp.2018.22.29.
[126] United Nations, "African countries by population, Worldometers.info, https://www.worldometers.info/population/countries-in-africa-by-population/, 2023. (Accessed 21 December 2023).
[127] F.V. Bekun, A.A. Alola, Determinants of renewable energy consumption in agrarian Sub-Sahara African economies, Energy Ecol. Environ. 7 (3) (Jun. 2022) 227–235, https://doi.org/10.1007/s40974-022-00243-8.
[128] M.J. Brooks, et al., SAURAN: a new resource for solar radiometric data in Southern Africa, J. Energy South Afr. 26 (1) (Feb. 2015) 2–10, https://doi.org/10.17159/2413-3051/2015/v26i1a2208.
[129] UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (UNCTAD), World Investment Report 2023, Jul. 2023 [Online]. Available: https://unctad.org/publication/world-investment-report-2023. (Accessed 15 October 2023).
[130] IRENA and AfDb, Renewable Energy Market Analysis: Africa and its Regions, Abu Dhabi and Abidjan, 2023.
[131] N.M. Haegel, S.R. Kurtz, Global progress toward renewable electricity: tracking the role of solar (Version 3), IEEE J. Photovoltaics 13 (6) (Nov. 2023) 768–776, https://doi.org/10.1109/JPHOTOV.2023.3309922.
[132] International Energy Agency, World energy investment 2022 [Online]. Available: https://www.iea.org/reports/world-energy-investment-2022, Jun. 2022. (Accessed 15 October 2023).
[133] Biogas Market, Global biogas market by source [Online]. Available: https://market.us/report/biogas-market/, Oct. 2023. (Accessed 7 November 2023).
[134] ECEEE, Africa climate summit is vital moment for continent to take charge, ECEEE (2023) [Online]. Available: https://www.eceee.org/all-news/news/africa-climate-summit-is-vital-moment-for-continent-to-take-charge/. (Accessed 30 October 2023).
[135] Suneeta Kaimal, Aaron Sayne, Three steps toward an equitable energy transition [Online]. Available: https://resourcegovernance.org/articles/three-steps-toward-equitable-energy-transition, Nov. 05, 2021. (Accessed 20 October 2023).
[136] K. B. N. B. L. C, Challenging fossil fuel expansion, in: *Organising Responses to Climate Change*, Reclaim Finance, Cambridge University Press, 2022, pp. 64–84, https://doi.org/10.1017/9781009266901.004.
[137] International Energy Agency, Doubling energy investment in Africa requires urgent action to bring down financing costs and boost access to capital [Online]. Available: https://www.iea.org/news/doubling-energy-investment-in-africa-requires-urgent-action-to-bring-down-financing-costs-and-boost-access-to-capital, Sep. 2023. (Accessed 15 October 2023).
[138] African Development Bank, Financing a just transition in Africa: challenges and opportunities [Online]. Available: https://www.afdb.org/sites/default/files/2022/12/09/financing_a_just_transition_in_africa-challenges_and_opportunities_final_1_2.pdf, Dec. 2022. (Accessed 4 November 2023).
[139] Wasiu Abiola Owoola, Babatunde Alaba Olaniyo, Okwe Daniel Obeka, Ark Oluwatobi Ifeanyi, Olukayode B. Ige, Sakiru Folarin Bello, Cross-Sector collaboration in energy infrastructure development: new models for public-private partnerships in emerging markets, Inter. J. Sci. Res. Archive 13 (1) (Oct. 2024) 2871–2882, https://doi.org/10.30574/ijsra.2024.13.1.2020.
[140] D. Kırıkkaleli, T.S. Adebayo, Do public-private partnerships in energy and renewable energy consumption Matter for consumption-based carbon dioxide emissions in India? Environ. Sci. Pollut. Control Ser. (2021) https://doi.org/10.1007/s11356-021-12692-5.
[141] Lake Turkana Wind Power Ltd, "The Lake Turkana Wind Power (LTWP) Project" Lake Turkana Wind Power Ltd. Accessed: January. 6, 2025. [Online]. Available: https://ltwp.co.ke/.
[142] Akinwumi Adesina, GEAPP, rockefeller foundation, SEforALL advance World Bank & AfDB mission to electrify 300 million in Africa [Online]. Available: https://www.afdb.org/en/news-and-events/geapp-rockefeller-foundation-seforall-advance-world-bank-afdb-mission-electrify-300-million-africa-74304, Sep. 2024. (Accessed 6 January 2025).
[143] African Development Bank Group, Africa's economic growth to outpace global forecast in 2023-2024 (Jan. 2023).
[144] B. Skosana, An evaluation of potential strategies in renewable energy systems and their importance for South Africa—a review, Energies (Basel) (2023), https://doi.org/10.3390/en16227622.
[145] A.K. Aliyu, B. Modu, C.W. Tan, A review of renewable energy development in Africa: a focus in South Africa, Egypt and Nigeria, Renew. Sustain. Energy Rev. 81 (Jan. 2018) 2502–2518, https://doi.org/10.1016/j.rser.2017.06.055.
[146] P.D. Necoechea-Porras, A. López, J.C. Salazar-Elena, Deregulation in the energy sector and its economic effects on the power sector: a literature review, Sustainability 13 (6) (Mar. 2021) 3429, https://doi.org/10.3390/su13063429.
[147] A. Eberhard, R. Naude, The South African renewable energy independent power producer procurement Programme: a review and lessons learned, J. Energy South Afr. 27 (4) (Dec. 2016) 1, https://doi.org/10.17159/2413-3051/2016/v27i4a1483.
[148] Matti Supponen, Electricity Markets and Systems in the EU and China, Jun. 2020.
[149] Louisa Brooke-Holland, Coups and Political Stability in West Africa, vol. 9861, House of Commons Library, 2023.
[150] Axel van Trotsenburg, Breaking Down Barriers to Clean Energy Transition, The World Bank, May 16, 2023.
[151] Energy Charter, Enabling Foreign Direct Investment in the Renewable Energy Sector Reducing Regulatory Risks and Preventing Investor-State Conflicts, Apr. 2023.
[152] A. Akhmetov, A. Vundo, Assessment of the driving factors affecting electricity consumption in Africa using index decomposition analysis and satellite derived data, Eng. J. 22 (1) (Jan. 2018) 27–48, https://doi.org/10.4186/ej.2018.22.1.27.
[153] M.S. Ben Fares, S. Abderafi, Water consumption analysis of Moroccan concentrating solar power station, Sol. Energy 172 (Sep. 2018) 146–151, https://doi.org/10.1016/j.solener.2018.06.003.
[154] A. B. Z. L., L.A.A. Amale Laaroussi, Impact study of NOOR 1 project on the Moroccan territorial economic development, Renew. Energy Environ. Sustain. 6 (Apr. 2021).
[155] Power Technology, Noor ouarzazate solar complex [Online]. Available: https://www.power-technology.com/projects/noor-ouarzazate-solar-complex/, Mar. 2020. (Accessed 25 October 2023).
[156] A. Laaroussi, O. Laaroussi, A. Bouayad, Environmental impact study of the NOOR 1 solar project on the Southern Region of Morocco, Renew. Energy Environ. Sustain. 8 (Jul. 2023) 9, https://doi.org/10.1051/rees/2023007.
[157] Anton Eberhard, Raine Naude, THE SOUTH AFRICAN RENEWABLE ENERGY IPP PROCUREMENT PROGRAMME- Review, Lessons Learned & Proposals to Reduce Transaction Costs, 2019 [Online]. Available: https://www.gsb.uct.ac.za/files/EberhardNaude_REIPPPPReview_2017_1_1.pdf. (Accessed 1 November 2023).
[158] P.V. Magazine, REIPPP: one of the world's best renewable energy tenders, but there's room for improvement, PV Magazine (Sep. 30, 2021) [Online]. Available: https://www.pv-magazine.com/2021/09/30/reippp-one-of-the-worlds-best-renewable-energy-tenders-but-theres-room-for-improvement/. (Accessed 6 November 2023).
[159] South African Government, Renewable independent power producer Programme [Online]. Available: https://www.gov.za/about-government/government-programmes/renewable-independent-power-producer-programme. (Accessed 18 November 2023).
[160] Babalwa Bungane, "REIPPPP lessons," ESI Africa [Online]. Available: https://www.gov.za/about-government/government-programmes/renewable-independent-power-producer-programme. (Accessed 18 November 2023).
[161] SA News, "Renewable energy programme attracts R209.4 billion to SA economy".
[162] C. Rasmus Heltberg, RWANDA RENEWABLE ENERGY FUND PROJECT, Jun. 2022.
[163] I. Bisaga, P. Parikh, J. Tomei, L.S. To, Mapping synergies and trade-offs between energy and the sustainable development goals: a case study of off-grid solar energy in Rwanda, Energy Policy 149 (Feb. 2021) 112028, https://doi.org/10.1016/j.enpol.2020.112028.
[164] S, M.A. Collings, Pay-as-you-go solar PV in Rwanda: evidence of benefits to users and issues of affordability, Field Actions Sci. Rep. (15) (2016) 94–103.
[165] Wikipedia, Benban solar Park [Online]. Available: https://en.wikipedia.org/wiki/Benban_Solar_Park, Sep. 25, 2023. (Accessed 2 November 2023).
[166] A.S.A. Mohamed, H.M. Maghrabie, Techno-economic feasibility analysis of Benban solar Park, Alex. Eng. J. 61 (12) (Dec. 2022) 12593–12607, https://doi.org/10.1016/j.aej.2022.06.034.
[167] Climate Council, 11 countries leading the charge on renewable energy [Online]. Available: https://www.climatecouncil.org.au/11-countries-leading-the-charge-on-renewable-energy/, Aug. 2022. (Accessed 12 October 2023).
[168] Akinwumi Paul, Least developed countries cannot afford to strand their assets, given their development challenges, Geneva, Switzerland,, https://unctad.org/news/least-developed-countries-cannot-afford-strand-their-assets-given-their-development-challenges, 2021. (Accessed 17 November 2023).
[169] M. Ram, M. Child, A. Aghahosseini, D. Bogdanov, A. Lohrmann, C. Breyer, A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030, J. Clean. Prod. 199 (Oct. 2018) 687–704, https://doi.org/10.1016/j.jclepro.2018.07.159.
[170] BNEF, Cost of new renewables temporarily rises as inflation starts to bite [Online]. Available: https://about.bnef.com/blog/cost-of-new-renewables-temporarily-rises-as-inflation-starts-to-bite/, 2022. (Accessed 2 November 2023).
[171] IRENA, Renewable power remains cost-competitive amid fossil fuel crisis [Online]. Available: https://www.irena.org/news/pressreleases/2022/Jul/Renewable-Power-Remains-Cost-Competitive-amid-Fossil-Fuel-Crisis, 2022. (Accessed 3 November 2023).
[172] BNEF, 2H 2022 levelized cost of electricity update [Online]. Available: https://about.bnef.com/blog/2h-2022-levelized-cost-of-electricity-update/, 2022. (Accessed 3 November 2023).
[173] Nirina Letsara, Callixte Kambanda, Wale Shonibare, Estimating Investment Needs for the Power Sector in Africa 2016-2025, Sep. 2019.
[174] S.W. Ndiritu, M.K. Engola, The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya, Renew. Energy 161 (Dec. 2020) 593–605, https://doi.org/10.1016/j.renene.2020.07.082.

[175] O. Smith, S. Coombes, R.D. O'Dea, Stability analysis of electrical microgrids and their control systems, PRX Energy 3 (1) (Feb. 2024) 013011, https://doi.org/10.1103/PRXEnergy.3.013011.
[176] M.W. Rakib, A.H. Munna, T. Farooq, A. Boker, M. He, Enhancing grid stability and sustainability: energy-storage-based hybrid systems for seamless renewable integration, European J. Electr. Eng. Comput. Sci. 8 (3) (May 2024) 1–8, https://doi.org/10.24018/ejece.2024.8.3.618.
[177] IRENA, Renewable Capacity Statistics 2020, 2020.
[178] T. Chamarande, B. Hingray, S. Mathy, in: Reducing the Carbon Footprint of Mini-Grids in Africa: the Value of Solar PV, 2023, https://doi.org/10.5194/egusphere-egu23-3367.
[179] A.T. Carabajal, et al., Social and economic impact analysis of solar mini-grids in rural Africa: a cohort study from Kenya and Nigeria, Environ. Res.: Infrastruct. Sustain. 4 (2) (Jun. 2024) 025005, https://doi.org/10.1088/2634-4505/ad4ffb.
[180] A.H. Kazimierczuk, Wind energy in Kenya: a status and policy framework review, Renew. Sustain. Energy Rev. 107 (Jun. 2019) 434–445, https://doi.org/10.1016/j.rser.2018.12.061.
[181] Y. Zahraoui, A. Bouhanik, T.E. Khalil Zidane, P. Elia Campana, S. Mekhilef, Grid-forming technologies for resilient renewable energy integration into power systems: a review, in: 2024 International Conference on Smart Systems and Technologies (SST), IEEE, Oct. 2024, pp. 191–196, https://doi.org/10.1109/SST61991.2024.10755449.
[182] A.S. Ajagun, W. Mao, X. Sun, J. Guo, B. Adebisi, A.M. Aibinu, The status and potential of regional integrated energy systems in sub-Saharan Africa: an Investigation of the feasibility and implications for sustainable energy development, Energy Strategy Rev. 53 (May 2024) 101402, https://doi.org/10.1016/j.esr.2024.101402.
[183] A.S. Ajagun, W. Mao, X. Sun, J. Guo, B. Adebisi, A.M. Aibinu, The status and potential of regional integrated energy systems in sub-Saharan Africa: an Investigation of the feasibility and implications for sustainable energy development, Energy Strategy Rev. 53 (May 2024) 101402, https://doi.org/10.1016/j.esr.2024.101402.
[184] Hannah Ritchie, The price of batteries has declined by 97% in the last three decades, Our World in Data (2021) [Online]. Available: https://ourworldindata.org/battery-price-decline. (Accessed 6 January 2025).
[185] M.M.S. Ahmed, et al., Prospects and challenges of energy storage materials: a comprehensive review, J. Adv. Chem. Eng. 20 (Nov. 2024) 100657, https://doi.org/10.1016/j.ceja.2024.100657.
[186] H. Jafarizadeh, E. Yamini, S.M. Zolfaghari, F. Esmaeilion, M.E.H. Assad, M. Soltani, Navigating challenges in large-scale renewable energy storage: barriers, solutions, and innovations, Energy Rep. 12 (Dec. 2024) 2179–2192, https://doi.org/10.1016/j.egyr.2024.08.019.
[187] N.W. Ndlela, I.E. Davidson, A load flow analysis of the southern African power pool interconnections using high voltage AC, high voltage DC, and flexible AC transmission system, in: 2022 IEEE PES/IAS PowerAfrica, IEEE, Aug. 2022, pp. 1–5, https://doi.org/10.1109/PowerAfrica53997.2022.9905074.
[188] N.W. Ndlela, I.E. Davidson, K. Moloi, Power planning for a reliable southern african regional grid, Energies (Basel) 16 (3) (Jan. 2023) 1028, https://doi.org/10.3390/en16031028.
[189] G.G. Njema, R.B.O. Ouma, J.K. Kibet, A review on the recent advances in battery development and energy storage technologies, J. Renew. Energy 2024 (May 2024) 1–35, https://doi.org/10.1155/2024/2329261.
[190] A. Aghmadi, O.A. Mohammed, Energy storage systems: technologies and high-power applications, Batteries 10 (4) (Apr. 2024) 141, https://doi.org/10.3390/batteries10040141.
[191] N.W. Ndlela, I.E. Davidson, K. Moloi, Power planning for a reliable southern african regional grid, Energies (Basel) 16 (3) (Jan. 2023) 1028, https://doi.org/10.3390/en16031028.
[192] Financial aggregation for distributed renewable energy in East Africa regional assessment and action plan united nations development Programme [Online]. Available: https://www.undp.org/climate-aggregation-platform, 2024.
[193] A. Tejerina, Africa energy 2024 global business reports [Online]. Available: https://rb.gy/e41vax, 2024.
[194] United Nation, Climate change is an increasing threat to Africa [Online]. Available: https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa, Oct. 27, 2020. (Accessed 6 November 2023).
[195] World Economic Forum, Global risks report 2023, Switzerland, https://www.weforum.org/publications/global-risks-report-2023, Jan. 2023. (Accessed 3 November 2023).
[196] D. Lindvall, Democracy and the Challenge of Climate Change, International Institute for Democracy and Electoral Assistance, 2021, https://doi.org/10.31752/idea.2021.88.
[197] Z. Liu, Z. Gu, K. Ma, S. Yang, N. Xie, Life cycle assessment and economic analysis of sustainable ammonia production from biomass, Ind. Eng. Chem. Res. 62 (46) (Nov. 2023) 19752–19763, https://doi.org/10.1021/acs.iecr.3c03430.
[198] A.I. Osman, et al., Life cycle assessment and techno-economic analysis of sustainable bioenergy production: a review, Environ. Chem. Lett. 22 (3) (2024) 1115–1154, https://doi.org/10.1007/s10311-023-01694-z.
[199] R. Sacchi, et al., PRospective EnvironMental Impact asSEment (premise): a streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models, Renew. Sustain. Energy Rev. 160 (May 2022), https://doi.org/10.1016/j.rser.2022.112311.
[200] N. Kilinc-Ata, M. Alshami, K. Munir, How do strategic mineral resources affect clean energy transition? Cross-sectional autoregressive distributed lag (CS-ARDL) approach, Mineral Economics 36 (4) (Dec. 2023) 643–654, https://doi.org/10.1007/s13563-023-00373-3.
[201] F. Müller, M. Neumann, C. Elsner, S. Claar, Assessing african energy transitions: renewable energy policies, energy justice, and SDG 7, Polit. Govern. 9 (1) (Feb. 2021) 119–130, https://doi.org/10.17645/pag.v9i1.3615.
[202] M. Addaney, B. Kengni, Energy transitions and the emerging energy law in Africa, in: Handbook of Energy Law in the Low-Carbon Transition, De Gruyter, 2023, pp. 277–290, https://doi.org/10.1515/9783110752403-024.
[203] World Economic Forum, Fostering effective energy transition 2023, Switzerland, https://www.weforum.org/publications/fostering-effective-energy-transition-2023/, Jun. 2023. (Accessed 1 November 2023).
[204] P. Nweze, Renewable, non-renewable energy consumption, and economic growth: evidence from west African countries, African Econ. Manag. Rev. (2022), https://doi.org/10.53790/aemr.v2i1.26.
[205] D.L. McCollum, et al., Energy investment needs for fulfilling the Paris agreement and achieving the sustainable development goals, Nat. Energy 3 (7) (Jun. 2018) 589–599, https://doi.org/10.1038/s41560-018-0179-z.
[206] B. Lin, R. Sai, Sustainable transitioning in Africa: a historical evaluation of energy productivity changes and determinants, Energy 250 (Jul. 2022) 123833, https://doi.org/10.1016/j.energy.2022.123833.
[207] T. Simone, M. Bazilian, The role of international institutions in fostering sub-Saharan Africa's electrification, Electr. J. 32 (2) (Mar. 2019) 13–20, https://doi.org/10.1016/j.tej.2019.01.016.
[208] B.E.K. Nsafon, N.N. Same, A.O. Yakub, D. Chaulagain, N.M. Kumar, J.-S. Huh, The justice and policy implications of clean energy transition in Africa, Front. Environ. Sci. 11 (Jan) (2023), https://doi.org/10.3389/fenvs.2023.1089391.
[209] J. Gu, N. Renwick, L. Xue, The BRICS and Africa's search for green growth, clean energy and sustainable development, Energy Policy 120 (Sep. 2018) 675–683, https://doi.org/10.1016/j.enpol.2018.05.028.
[210] N. Scarlat, J.-F. Dallemand, F. Monforti-Ferrario, M. Banja, V. Motola, Renewable energy policy framework and bioenergy contribution in the European union – an overview from national renewable energy action plans and progress reports, Renew. Sustain. Energy Rev. 51 (Nov. 2015) 969–985, https://doi.org/10.1016/j.rser.2015.06.062.
[211] S.D. Agyeman, B. Lin, Nonrenewable and renewable energy substitution, and low–carbon energy transition: evidence from North African countries, Renew. Energy 194 (Jul. 2022) 378–395, https://doi.org/10.1016/j.renene.2022.05.026.
[212] T. Caetano, H. Winkler, J. Depledge, Towards zero carbon and zero poverty: integrating national climate change mitigation and sustainable development goals, Clim. Policy 20 (7) (Aug. 2020) 773–778, https://doi.org/10.1080/14693062.2020.1791404.
[213] B. Kareem, et al., Pathways for resilience to climate change in African cities, Environ. Res. Lett. 15 (7) (Jul. 2020) 073002, https://doi.org/10.1088/1748-9326/ab7951.
[214] M. Dal Maso, K.H. Olsen, Y. Dong, M.B. Pedersen, M.Z. Hauschild, Sustainable development impacts of nationally determined contributions: assessing the case of mini-grids in Kenya, Clim. Policy 20 (7) (Aug. 2020) 815–831, https://doi.org/10.1080/14693062.2019.1644987.
[215] C. Armstrong, D. McLaren, Which net zero? Climate justice and net zero emissions, Ethics Int. Aff. 36 (4) (Dec. 2022) 505–526, https://doi.org/10.1017/S0892679422000521.
[216] Climate Action Tracker, South Africa net zero target [Online]. Available: https://climateactiontracker.org/countries/south-africa/net-zero-targets/, Oct. 2022. (Accessed 18 November 2023).
[217] South Africa, IMF Staff Country Reports 2023 (195) (Jun. 2023) 1, https://doi.org/10.5089/9798400245350.002.
[218] Climate Action Tracker, Morocco net zero target [Online]. Available: https://climateactiontracker.org/countries/morocco/. (Accessed 18 November 2023).
[219] Climate Action Tracker, "The Gambia Net Zero Target".
[220] Climate Action Tracker, Kenya net zero target [Online]. Available: https://climateactiontracker.org/countries/kenya/. (Accessed 18 November 2023).
[221] P.L. Cichello, L. Mncube, M. Oosthuizen, L. Poswell, Economists versus the street: comparative viewpoints on barriers to self-employment in khayelitsha, South Africa, SSRN Electron. J. (2011), https://doi.org/10.2139/ssrn.2184230.
[222] Y. Abdul-Salam, E. Phimister, Modelling the impact of market imperfections on farm household investment in stand-alone solar PV systems, World Dev. 116 (Apr. 2019) 66–76, https://doi.org/10.1016/j.worlddev.2018.12.007.
[223] A.G. Dagnachew, P.L. Lucas, A.F. Hof, D.E.H.J. Gernaat, H.-S. de Boer, D.P. van Vuuren, The role of decentralized systems in providing universal electricity access in Sub-Saharan Africa – a model-based approach, Energy 139 (Nov. 2017) 184–195, https://doi.org/10.1016/j.energy.2017.07.144.
[224] H. Koranteng Nkansah, S. Suleman, I. Ackah, B.A. Amarh, D. Eduah, J.A. Jinapor, Determinants of electricity demand in Cote d'Ivoire, Ghana, Nigeria and Senegal, Energies (Basel) 15 (14) (Jul. 2022) 4998, https://doi.org/10.3390/en15144998.
[225] M. Rateau, A. Choplin, Electrifying urban Africa: energy access, city-making and globalisation in Nigeria and Benin, Int. Dev. Plan. Rev. 44 (1) (Jan. 2022) 55–80, https://doi.org/10.3828/idpr.2021.4.
[226] F.A. Oluleye, A.O. Koginam, Nigeria's energy sector privatization: reforms, challenges and prospects, South Asian j. Res. Humanit. Soc. Sci. 1 (2) (Aug. 2019) 189–197, https://doi.org/10.36346/sarjhss.2019.v01i02.028.
[227] Yetunde Adenike Adebayo, Augusta Heavens Ikevuje, Jephta Mensah Kwakye, Andrew Emuobosa Esiri, Energy transition in the oil and gas sector: business models for a sustainable future, Int. J. Manag. Enterp. Res. 6 (10) (Oct. 2024) 3180–3208, https://doi.org/10.51594/ijmer.v6i10.1611.
[228] A. Dosunmu, K.S. Olanrewaju, Energy transition and its implications on energy security in the major oil producing gulf of Guinea countries: Nigeria and Angola case study, European Modern Studies Journal 8 (3) (Jul. 2024) 387–397, https://doi.org/10.59573/emsj.8(3).2024.28.

[229] Uwaga Monica Adanma, Emmanuel Olurotimi Ogunbiyi, Assessing the economic and environmental impacts of renewable energy adoption across different global regions, J. Eng. Sci. Technol. 5 (5) (May 2024) 1767–1793, https://doi.org/10.51594/estj.v5i5.1154.

[230] J. Zhang, The economic benefits of renewable energy: impact on traditional energy markets, in: Highlights in Business, vol. 30, Economics and Management, Apr. 2024, pp. 352–359, https://doi.org/10.54097/0ddb2n81.

[231] J. Greenspon, D. Raimi, Matching geographies and job skills in the energy transition, Extr. Ind. Soc. 17 (Mar. 2024) 101397, https://doi.org/10.1016/j.exis.2023.101397.

[232] R. Hanna, P. Heptonstall, R. Gross, Job creation in a low carbon transition to renewables and energy efficiency: a review of international evidence, Sustain. Sci. 19 (1) (Jan. 2024) 125–150, https://doi.org/10.1007/s11625-023-01440-y.

[233] Jobs for a Livable Planet, Job Creation Potential of the Clean Energy Transition, World Bank, Washington, DC, 2024, https://doi.org/10.1596/40962.

[234] UNECA, African leaders call for more investments in green energy and water infrastructure, Africa Renew. (2023) [Online]. Available: https://www.un.org/africarenewal/magazine/july-2023/african-leaders-call-more-investments-green-energy-and-water-infrastructure. (Accessed 15 October 2023).

[235] World Economic Forum, Fostering Effective Energy Transition 2023, Jun. 2023.

[236] V. Pandey, A. Sircar, N. Bist, K. Solanki, K. Yadav, Accelerating the renewable energy sector through Industry 4.0: optimization opportunities in the digital revolution, Inter. J. Innovat. Stud. 7 (2) (Jun. 2023) 171–188, https://doi.org/10.1016/j.ijis.2023.03.003.

[237] Letters - A. Voyager, Blueprint for opportunity, Voyager (2022) [Online]. Available: https://www.voyagervc.com/news-and-letters/faster-every-day. (Accessed 2 November 2023).

[238] J. Zhou, A. Sun, Progress in the advancement of atomically dispersed catalysts for enhanced performance lithium-sulfur batteries, Chem. Eng. J. 488 (May 2024) 150719, https://doi.org/10.1016/j.cej.2024.150719.

[239] Global Witness, A rush for Lithium in Africa risks fuelling corruption and failing citizens, Nat. Resour. Govern. (2023) [Online]. Available: https://www.globalwitness.org/en/campaigns/natural-resource-governance/lithium-rush-africa. (Accessed 8 December 2023).

[240] World Bank, Mineral production to soar as demand for clean energy increases, WASHINGTON, https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases, May 2020. (Accessed 8 December 2023).

[241] B.F. Abrantes, M.T. Preto, N. Antonio, Unraveling collaborative learning stimuli and effective dynamic capability integration on MNCs: the global capabilities administration model (GCAM), Review Int. Bus. Strat. 33 (2) (Jan. 2023) 272–300, https://doi.org/10.1108/RIBS-06-2021-0085.

[242] Y. Li, Y. Wang, L. Wang, J. Xie, Investigating the effects of stakeholder collaboration strategies on risk prevention performance in a digital innovation ecosystem, Ind. Manag. Data Syst. 122 (9) (Oct. 2022) 2045–2071, https://doi.org/10.1108/IMDS-12-2021-0805.

[243] C.L.P. Holdings, Focusing on the future, today (2023).

[244] K.E. Bassey, C. Agupugo, J. Aigbovbiosa, C.P. Agupugo, Risk management strategies in renewable energy investment, Int. J. Novel Res. Eng. Sci. 11 (2024) 138–148, https://doi.org/10.5281/zenodo.13311076.

[245] I, U. Res, TOWARDS A PROSPEROUS AND SUSTAINABLE AFRICA, IRENA, Rome, 2022 [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RES4Africa_UNECA_Prosperous_Sustainable_Africa_2022_.pdf. (Accessed 6 November 2023).