



A RETROSPECT OF ENERGY DEMAND AND POTENTIAL OF SUB-SAHARAN AFRICA: LEVERAGING ENERGY DEFICIT TO ATTAIN CLEAN ENERGY HUB REGION

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The lack of reliable energy access is a significant obstacle to the socio-economic progress of the Global South, particularly sub-Saharan Africa (SSA). This research explores the current energy demand and access situation, evaluated SSA's renewable energy (RE) potential, identifies barriers to RE development, and proposed strategies to overcome these challenges. The study emphasises the importance of establishing RE infrastructure for a sustainable energy transition and outlined necessary investments. With an impressive 11,000 gigawatts (GW) of exploitable generating capacity, RE has the potential to replace fossil fuels effectively in SSA. The dominant resources are solar (10 TW), hydro (350 GW), wind (110 GW), and geothermal (15 GW) energy. Challenges include high initial costs, limited financing access, grid integration issues, infrastructure deficiencies, regulatory frameworks, and resource variability. To address these challenges, the study suggests policy and regulatory reforms, expanded financing access, capacity building, and improved grid infrastructure. Overall, this research presents the energy deficit and RE potential in SSA as opportunities for the region to become a clean energy hub, requiring collaboration among governments, academic institutions, industry stakeholders, and international organizations.

1.0 Introduction

Sub-Saharan Africa (SSA) ranks as the world's least electrified region, with just 48% having access to electricity and a mere 17% having access to clean cooking facilities (Ramalope et al., 2022). As a result, traditional biomass continues to play a significant role in SSA, constituting nearly half of the region's primary energy mix (IEA, 2022, IRENA and AfDB, 2022). In 2019, the top 20 countries with the most significant energy access deficits globally were situated in the Global South (Azeez, 2021). These included six in Eastern and South-Eastern Asia, ten in SSA, and four in Central and Southern Asia. However, over the past decade, more than one billion people have gained access to electricity. The COVID-19 pandemic temporarily reversed this progress, leaving around 30 million people unable to afford basic electricity, with the majority residing in SSA (IEA et al., 2021). Consequently, in some SSA countries like the Democratic Republic of Congo, Ethiopia, Madagascar, Mozambique, Tanzania, Niger, and Uganda, only 5% of the population does not rely on charcoal and wood for cooking (WHO, 2021). The prolonged electricity deficiency in SSA shows no sign of abating, as rapid population growth, urbanisation, and industrialisation continue to challenge efforts to address this issue. The highest rates of urbanisation are expected in the Global South, specifically in the African and Asian regions.

The top 20 countries facing the most significant challenges in providing electricity accounted for 75% of the global population in 2021. The countries with the largest populations lacking access were Nigeria (86 million), the Democratic Republic of the Congo (76 million), and Ethiopia (55 million) (IEA et al., 2023). From 2019 to 2021, the Democratic Republic of the Congo experienced a situation where its progress in electrification lagged behind its population growth, resulting in an increase in the number of people without access to electricity in the country. In contrast, Nigeria and Ethiopia saw their electrification efforts outpace their population growth rates. Among countries with limited access to electricity, Kenya and Ethiopia exhibited the most rapid improvement, with both nations extending electrification by more than 3 percentage points annually between 2019 and 2021 (IEA et al., 2023).

Over the past decade, a larger portion of the world's population achieved electricity access than ever before (Worldbank, 2022, Streatfeild, 2018b). However, it is worth noting that the number of people without electricity in SSA has risen.

The global community is expected to continue facing challenges in achieving its objective of ensuring universal access to affordable, reliable, sustainable, and modern energy by 2030. This goal may remain elusive unless significant actions are undertaken to enhance access in nations experiencing the most pronounced energy deficits. This was the common position of notable international organisations, such as the International Renewable Energy Agency (IRENA), the United Nations Department of Economic and Social Affairs (UN DESA), and the World Bank, according to the International Energy Agency (IEA) Energy Progress Report (Worldbank, 2021b, ESMAP, 2023). The consequences of this energy deficit in SSA include escalating CO₂ emissions, deforestation, ecosystem disruption, health problems, climate change, loss of biodiversity, inhibited economic growth, and worsening poverty levels in the region (Afful-Dadzie et al., 2020, Bloomer and Boateng, 2024, Byaro et al., 2024,). These challenges are not only peculiar to SSA, they are worldwide issues, driven by the need for energy to fuel socioeconomic development. In response to this crisis, a global initiative led by the United Nations (UN) to combat CO₂ emissions has emerged, to reduce or eliminate CO₂ emissions (UNEP, 2023).

Nevertheless, man will not let go of “fossil fuel” without an appropriate or better alternative because of economic reasons. A reduction in the use of fossil fuel without an appropriate substitute will not work (Ebhota, 2019b). It means a decline in economic activities, which could exacerbate the challenge of meeting energy demands in energy-poor countries due to the existing power deficit (Ebhota and Tabakov, 2019). Renewable energy is expected to be an alternative source devoid of complication and compromise. However, despite the declining costs of clean energy alternatives, they are relatively high in the global south, especially the initial cost. This coupled with other technical challenges, such as power intermittency and low power conversion efficiency slow down RE deployment and hinder the universal energy access progress.

This study identified the research gaps and areas of interest about SSA's energy status, RE potential, and transition to RE that need to be studied, understood, and addressed. This is necessary if RE potential is to be developed and deployed to change the present narrative of the region's perennial energy access issues. The research gaps and areas of interest in energy and sustainable energy transition are behavioural and cultural aspects, resilience and energy

security, technological innovation, and community engagement and participation (Bulbulia, 2022). Others are socioeconomic impacts, cross-border energy trade, energy storage technologies, climate change mitigation, data availability and quality, policy and regulatory frameworks, infrastructure development, energy efficiency, energy transition pathways, RE potential, energy access and inequality (Ganesan, 2024, IEA, 2009). However, the scope of this paper covers energy access, RE potential, infrastructure development, socioeconomic impacts, and technological innovation.

Tackling these research voids will aid in crafting evidence-backed policies and strategies fostering sustainable energy access, economic growth, and environmental conservation in SSA. Hence, this study analysed SSA's energy demand, access status, RE potential, identified RE development hurdles, and proposed countermeasures. It also underscores the significance of RE infrastructure development in achieving a sustainable energy transition, addressing investment requirements, with specific attention to the African Development Bank's (AfDB) role.

1. Examining energy demand, generation, and supply in SSA

Globally, about 1.2 billion people were without access to electricity in 2019 and they lived mostly in the Global South; 50% of the global population without access live in SSA (IEA, 2021b, IEA, 2020, Routley, 2019). Again in 2021, according to the Economic Commission for Africa (ECA) - SSA had a 72% (about 600 million) share of the 900 million people that lack access to electricity globally (ECA, 2021); 80-86% of the energy consumed in SSA is of solid biomass - for cooking and 78% of oil is consumed in the transport sector (ECA, 2021). Several efforts are being made to increase the population with access to electricity in the region. About 80 GW was the installed electricity capacity in SSA (excluding South Africa) in 2018, which is approximately three times less than that of France. The generated net electricity in Africa in 2019 was only 804 terawatts-hour (TWh), about 20% of that of the United States that same year. Africa experienced about a 2.5% decline in the electricity generation in 2020 (from 863 TWh in 2019 to 844 TWh in 2020) (AEC, 2021). Eleven countries accounted for three-quarters of the energy demand and gross domestic product (GDP) of SSA in 2018 (IEA, 2019a). The share of the primary energy sources and the eleven countries that accounted for the three-quarters are presented in Figure 1(a) and (b), respectively.

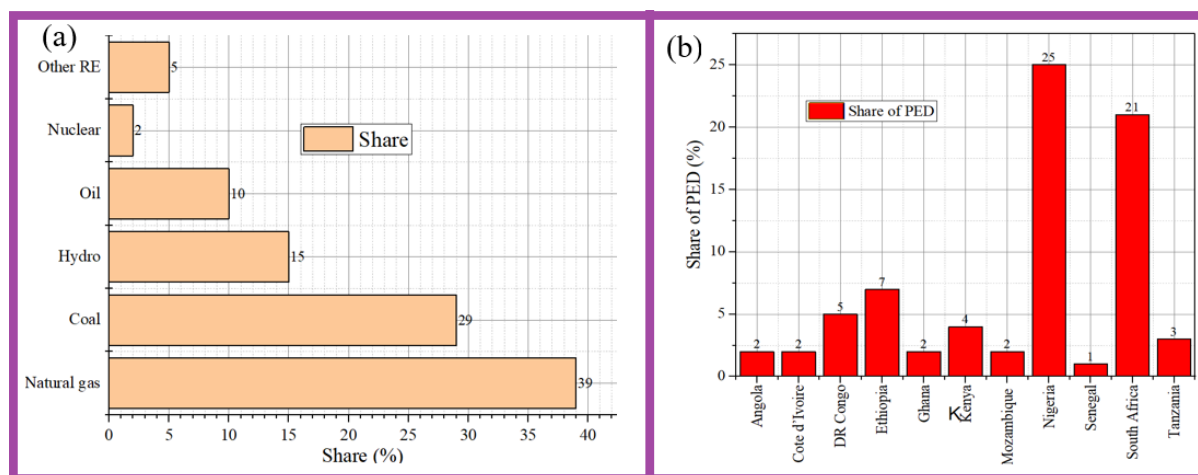


Figure 1: Shares of SSA primary energy demand (PED); (b) SSA countries that accounted for the three-quarters in 2018 (IEA, 2019a)

In 2021, power demand in SSA saw a notable growth of more than 5%, bouncing back from a 4% decline the previous year, which was primarily caused by disruptions and economic slowdown due to the COVID-19 pandemic (IEA, 2021a). The recovery in demand was primarily driven by the commercial and industrial sectors, which experienced growth rates of approximately 4% and 8%, respectively. Residential demand also rebounded, even though it did not decline in 2020, unlike the other segments of demand. The projection is that the overall power demand will continue to grow in 2022, although at a slower pace compared to 2021 if new waves of COVID-19 variants do not severely impact economic activity. It is noteworthy that power demand in SSA remains relatively low, with an average of less than 500 kWh per capita, which is among the lowest levels globally (Berkove et al., 2022). In 2020, South Africa was responsible for about half of SSA's total power demand and experienced a significant drop in demand due to both the COVID-19 pandemic and scheduled power cuts, worsened by the country's ongoing power supply crisis. However, South Africa managed to recover its power demand to pre-pandemic levels in 2021, thanks to a rapid rebound in the industrial sector, which saw an 8% year-on-year increase in demand. Nigeria, the second-largest power market in SSA, accounting for nearly 11% of the region's total power demand, continues to face challenges with suppressed power demand, largely due to persistent supply issues and low electrification rates (Berkove et al., 2022, IEA, 2022). Although Nigeria's power demand recovery in 2021 was driven by the commercial and industrial sectors, it is important to note that roughly half of the country's total power demand comes from off-grid sources (EIA, 2022).

Electricity demand in SSA is a critical topic due to the region's population growth, urbanisation, and economic development. The demand for energy in Africa has been on a steady rise, increasing at an annual rate of approximately 3%, surpassing all other continents (PwC, 2022). Having access to reliable electricity is a prerequisite for igniting industrialisation and meaningful economic growth. The global electrification rate has increased significantly since 2000, but SSA has not seen much progress in this regard. The actual energy supply continues to significantly fall short of meeting the demand in the region. As of 2021, SSA accounted for about 80% of the world's population without electricity access, and 19 of the 20 countries with the lowest electrification rates were located in this region (Statista, 2023). The only exception was Haiti, a Caribbean country. Furthermore, there are significant disparities in access within the region, with over 80% of the urban population in the region having electricity access in 2021, while only 30% of those living in rural areas enjoyed the same privilege. Across the region, customers are burdened by consistently poor power supply reliability. As of April 2022, a survey revealed that only 43% of Africans reported having access to a dependable electricity supply, which is a modest increase of just 3% points since 2015. The level of electricity access across African countries is shown in Figure 2.

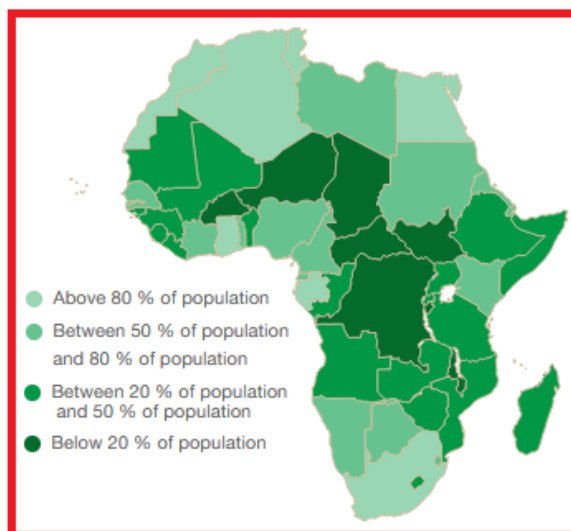


Figure 2: Level of electricity access in African countries (% of the population) (AEP, 2022).

The most recent data from the World Bank Enterprise Surveys indicates that customers in SSA endure an average of nine power outages per month, each lasting an average of 5.7 hours, as presented in Table I (Statista, 2023, Worldbank, 2020a). This lack of consistent and reliable power supply, especially for commercial and industrial users, exerts a disproportionate impact on economic productivity. Sub-Saharan African businesses frequently cite inadequate or unreliable power supply as a significant constraint, with majority of countries reporting that more than 50% of firms experience electrical disruptions (Garg et al., 2022). Approximately 41% of African firms identify the lack of electricity or its poor quality as a major constraint on their operations (Oseni, 2019). This compels these firms to resort to more environmentally harmful and expensive alternatives like diesel generators. This reliance on diesel generators has detrimental effects on firm efficiency and undermines competitiveness. Furthermore, approximately 28% of connected households experience power outages either occasionally or never have access to electricity (Lee et al., 2022).

Table I: Countries with the lowest electricity access

Country	Electricity access (%)	Annual electrical outages (%)	Country	Electricity access (%)	Annual electrical outages (%)
South Sudan	7.7	15.30	Guinea Bissau	35.8	84.20
Burundi	10.2	85.1	Benin Rep	42	95.6
Chad	11.3	70.20	Tanzanian	42.7	85.80
Malawi	14.2	82.90	Mozambique	31.5	52.80
CAR	15.7	89.00	Uganda	45.2	81.50
Niger	18.6	78.00	Zambia	46.7	87.10
Burkina Faso	19	91.90	Guinea	46.8	84.20

DRC	20.8	Not available	Haiti	47.2	Not available
PNG	20.9	97.7	Mauritania	47.7	90.70
Sierra Leone	27.5	71.80	Angola	48.2	87.70
Liberia	29.8	44.30	Rwanda	48.7	39
Madagascar	35.1	86.90			

(Statista, 2023, Worldbank, 2020a)

Electricity access in SSA has historically faced numerous challenges, notwithstanding being an essential component for economic development and improving the quality of life for its citizens. Despite decades of efforts and investments in electrification, SSA has the lowest rates of electricity access in the world. According to the IEA, over half of the global population without electricity access lives in SSA (IEA, 2019b). A significant portion of the population, particularly in rural areas, lacks access to electricity (Casati et al., 2023, Shettima et al., 2023). Even in areas with access to electricity, power supply is often unreliable, leading to frequent blackouts and disruptions. This inconsistency hampers economic activities and quality of life. The level of access to electricity across Africa and the rate of energy access increase in SSA are shown in Figure 3.

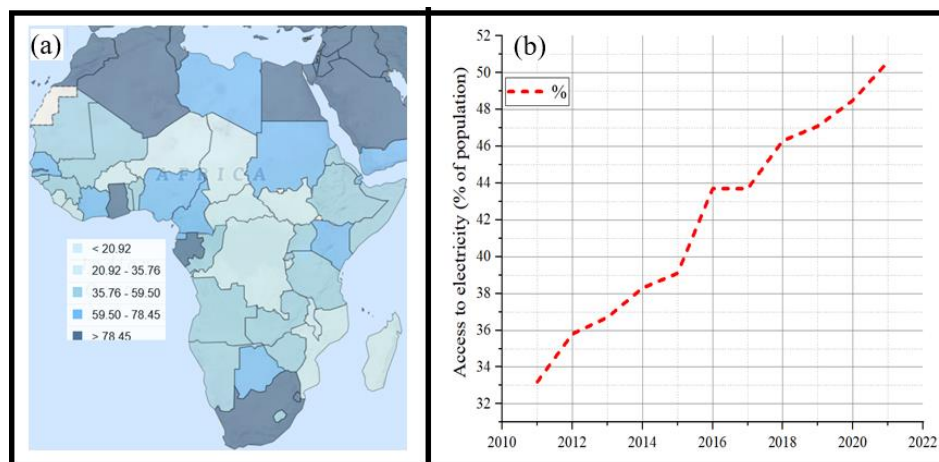


Figure 3: (a) The level of access to electricity across Africa; (b) SSA rate of energy access increase (WorldBank, 2021a).

1.1. Dynamics of SSA electricity demand increase

About 1.2 TWh was the projected total amount of electricity required by SSA in 2022, which is a 5% increase from the previous year. This estimate was based on the expected growth of population, economic activity, and electrification rate in the region. The main sources of electricity generation in SSA are hydro, thermal, and RE, with varying shares depending on the country and the availability of resources. The challenges faced by SSA in meeting its electricity demand include inadequate infrastructure, low access rates, high costs, and environmental impacts (Hafner et al., 2018, Emeterie et al., 2021). Electricity demand dynamics in SSA are influenced by a combination of factors that shape the region's energy landscape. The demand for both modern and traditional fuels will continue to exist, and population and urbanisation growth will play key factors in the demand increase. In SSA, there are other factors that to be considered in determining the electricity demand increase. It is important to note that SSA is

a diverse region with variations in electricity demand patterns from country to country, and some key aspects of SSA's electricity demand dynamics are presented in Table 2.

Table 2: SSA electricity demand dynamics.

Population growth	SSA has one of the fastest-growing populations globally. This demographic trend directly affects electricity demand, as more people require access to electricity for residential, commercial, and industrial purposes. The population growth rate of SSA was 2.57% in 2021 (O'Neill, 2023).
Urbanisation	Urban areas in SSA are expanding rapidly, leading to increased energy consumption. Urban centres typically have higher energy needs due to the concentration of economic activities, industries, and infrastructure (Gutu Sakketa, 2023).
Economic development	Economic growth and development are closely tied to electricity demand. As economies in SSA grow, so does the demand for energy to power industries, businesses, and services.
Industrialisation	Many countries in SSA are working towards industrialization and manufacturing growth. These sectors require significant amounts of electricity to operate machinery and facilities
Commercial and residential needs	Urbanization and economic growth drive the demand for electricity in commercial establishments, office buildings, and residential areas for lighting, heating, cooling, and electronic devices
Electrification of rural areas	Efforts to extend electricity access to rural and remote areas contribute to increasing demand. Rural electrification initiatives aim to improve living standards and stimulate economic activities
Energy access	A significant portion of SSA's population still lacks access to reliable electricity. Efforts to increase energy access contribute to rising electricity demand.
Technological advancements	As technology becomes more prevalent, the demand for electronic devices, communication tools, and digital services also drives electricity consumption.
Infrastructure development	Infrastructure projects, such as transportation systems, telecommunications networks, and modern facilities, require electricity for operation.

Energy-intensive sectors	Certain sectors, such as mining and mineral processing, can have high energy demands due to the energy-intensive nature of their operations.
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(Espoir et al., 2023, Fotio et al., 2023, Garg et al., 2022, Kondi-Akara et al., 2023)

1.2. Impact of efficiency on energy demand

Efficiency plays a crucial role in moderating the growth in demand, lessening reliance on fuel imports, easing the burden on existing infrastructure, and maintaining reasonable consumer energy costs. By 2030 (IEA, 2022), energy and material efficiency measures are expected to reduce electricity demand by 230 terawatt-hours, which accounts for 30% of the current electricity demand. Most of these savings, constituting 60%, are attributed to building codes and energy performance standards that limit the sale of the least efficient appliances and lighting.

1.3. Population and urbanisation

The rapid population increase of SSA strains infrastructure, making it more susceptible to disruptions. The concentration of industries, commercial establishments, and technology-intensive activities in cities, which come with urbanisation, increases electricity consumption and makes the area vulnerable to power outages due to the cascading effects of infrastructure failures or natural disasters. The continued urbanization and population rapid growth (O'Neill, 2022, O'Neill, 2023), as shown in Figure 4, in the region have a profound impact on electricity systems, influencing demand, infrastructure development, environmental sustainability, and equity in access. Managing these influences effectively is essential for meeting the energy needs of urban populations while striving for a sustainable and resilient energy future. Transitioning to cleaner and more efficient energy sources is a key component of addressing these challenges. Understanding and managing these dynamics is crucial for ensuring a stable and sustainable electricity supply in SSA. Policymakers, energy providers, and stakeholders must work together to meet the region's growing electricity demand while promoting energy efficiency, cleanliness, and sustainability.

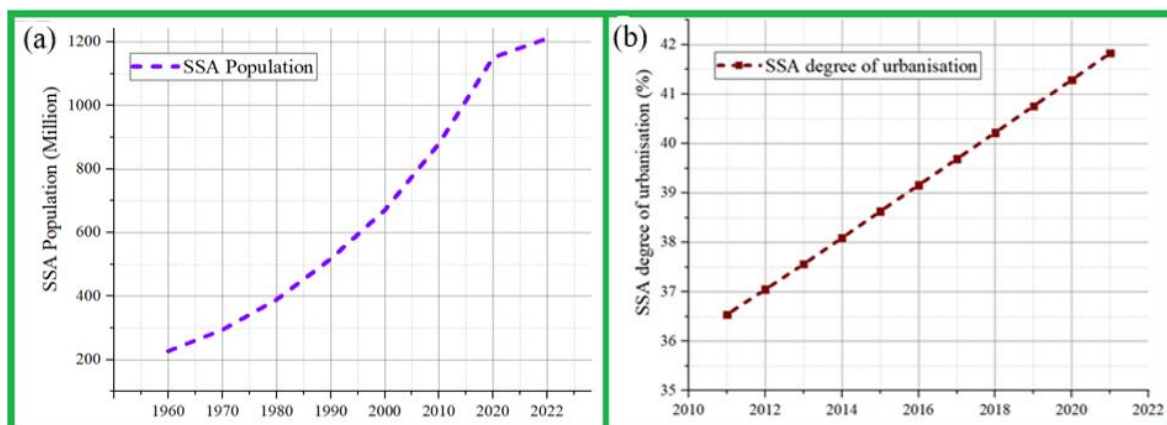


Figure 4: Sub-Saharan Africa (a) population from 1960-2022 (O'Neill, 2023); (b) degree of urbanization from 2011-2022 (O'Neill, 2022).

2. Leveraging energy deficit into clean energy hub

Leveraging SSA's energy deficit and RE's potential to transform the region into a clean energy hub is a visionary goal that can have significant socioeconomic, environmental, and social benefits. Additionally, it will job creation, and climate change mitigation efforts. This transformation requires a multi-faceted approach involving governments, the private sector,

international organizations, and local communities. It should be driven by a shared commitment to sustainable development, environmental protection, and improved energy access for all. Building RE infrastructure as the primary source of electricity generation can position SSA as a leader in clean energy development while meeting its energy needs for socioeconomic development. This transformation involves a comprehensive and integrated approach that encompasses policy, feasibility studies of the various RE sources, technology, finance, and community engagement to overcome the challenges and harness the benefits of this transformation.

2.1. Sub-Saharan African renewable energy potential

Despite the advantages of renewable options costs decline and the vast potential for RE sources, such as wind, solar, hydro, and geothermal, in the region, SSA has the least energy access globally. In 2019, the electrification rate in SSA stood at 46%, leaving 906 million people without access to clean cooking fuels and technologies (IRENA and AfDB, 2022). Sub-Saharan Africa has one of the world's lowest rates of electricity access, with over 600 million individuals lacking reliable electricity. Hence, the region heavily depends on imported fossil fuels, which can result in energy supply disruptions and price fluctuations. Renewable energy sources, being indigenous and sustainable, enhance energy security by reducing dependence on imported fuels. Renewables play a pivotal role in increasing access to electricity and clean cooking fuels. Africa's vast resource potential in wind, solar, hydro, and geothermal energy, and the declining costs are making renewables more accessible (Ebhota, 2019a, Ebhota, 2019b) . However, the expansion is relatively low, which means Africa's abundant resource potential is grossly untapped (Du et al., 2021, Zakari et al., 2022). The renewable power generation in Africa is relatively low, among the least continents considering what Europe and North America generate, as shown in Figure 5(a). Among the countries in Africa, South Africa and Northern Africa countries lead the chart in RE generation while West African countries are among the least RE generators, as presented in Figure 5(b).

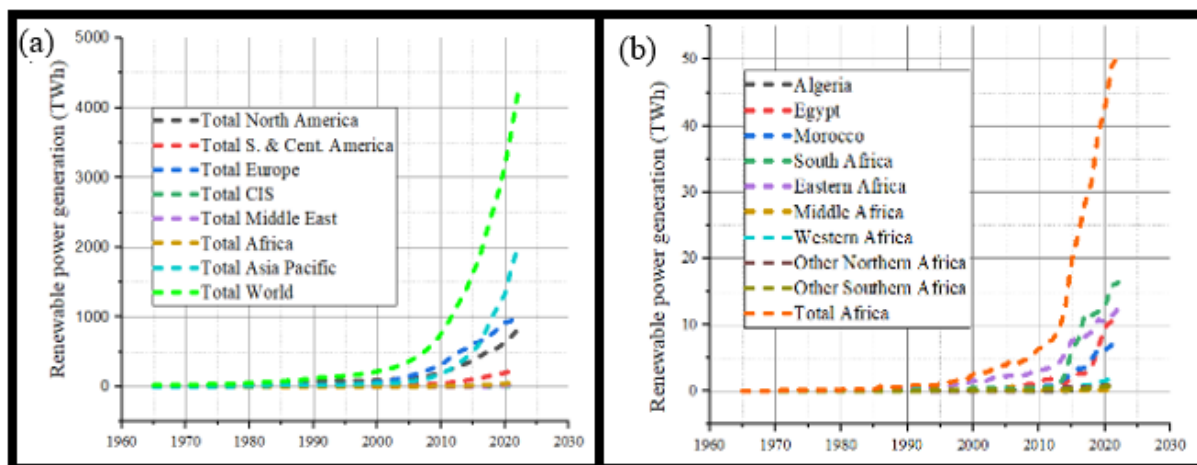


Figure 5: Renewable power generation across (El, 2024) (a) regions; (b) Africa.

Where Commonwealth of Independent States (CIS).

Africa boasts abundant RE resources, estimated to be around 1,000 times greater than the expected electricity demand by 2040 (Ramalope et al., 2022). This surplus of RE potential, equivalent to 11,000 gigawatts (GW) of exploitable generating capacity, positions the continent well to fulfil both its current and future energy requirements (AfDB, 2023). Figure 6 illustrates the distribution and capacity of these RE resources across Africa. Considering the imperative

to reduce pollution-related health issues, address energy crises, and combat climate change, there is an increasing need to shift from fossil fuels to RE sources. This transition represents a crucial energy paradigm shift comprising various intricate elements, with the effective management of these elements serving as the foundation for achieving sustainable energy transition (SET). Among these elements are digitization, decarbonization, and decentralization. This transition comes at a pivotal moment for SSA, which faces a significant energy deficit, exacerbating the region's challenges.

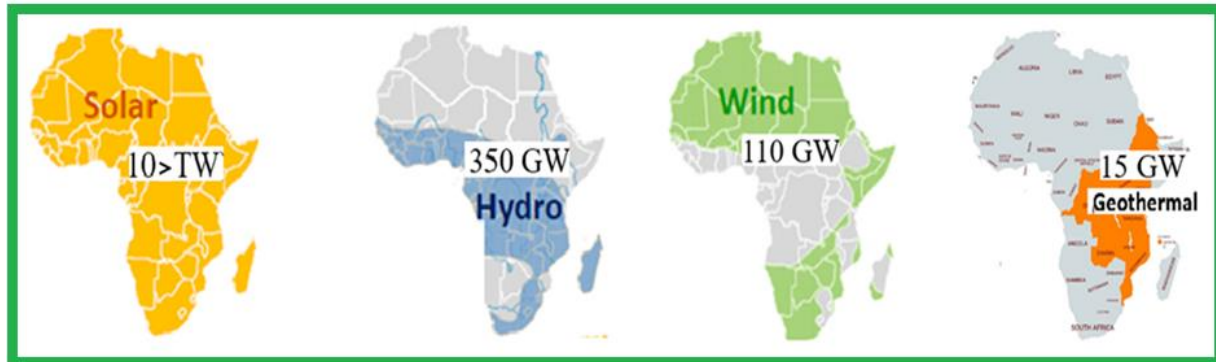


Figure 6: The distribution of RE across Africa (AfDB, 2018).

As per a study conducted by the IEA, RE is poised to contribute to nearly half of the growth in power production in SSA by the year 2040. The estimate of the technical potential per technology of SSA is presented in Table 3. The report of IEA highlights that while SSA's economy has been expanding steadily since 2000, this growth is hindered by the fact that a huge population in the region lacks access to electricity (IEA, 2021b). The study predicts that SSA will gradually unlock its vast RE resources over the next 26 years, with solar energy taking the lead in the RE sector. Interestingly, only 10% of the region's hydropower capacity is currently being utilized, according to the survey. Moreover, most of Africa boasts excellent solar energy potential, while coastal regions have significant wind energy potential. In countries like Kenya and Ethiopia, geothermal energy is emerging as the second-largest source of power (Waitzman, 2023, Benti et al., 2023, Chhun et al., 2023). By 2040, solar photovoltaics (PVs), small-scale hydropower, and wind energy will account for two-thirds of mini-grid and off-grid systems in rural areas (IRENA, 2015). As RE technologies costs continue to decrease relatively, RE systems become more attractive alternatives to diesel generators. However, in many cases, they are used in conjunction with diesel generators, particularly when there is adequate financing available to cover the higher initial costs.

Table 3: SSA technical potential per technology (Ramalope et al., 2022)

RE source	Capacity TWh/y	RE source	Capacity TWh/y	RE source	Capacity TWh/y	RE source	Capacity TWh/y	RE source	Capacity TWh/y
Solar PV	1,449,742	Hydropower	1,478	Biomass	2,374	Wind	978,066	Geothermal	105

A study conducted at the University of California, Berkeley, shows that there are considerable opportunities for the deployment of RE in Africa. The mapping out of the RE source locations in Northern, Central, Eastern, and Southern Africa shows a vast potential but is not uniformly

distributed across the regions (Wu et al., 2017). Hydropower, solar PV, and wind energy technologies denominate RE sources and offer decentralised and off-grid solutions, facilitating access to remote and underserved communities. According to IRENA’s report on RE market (IRENA and AfDB, 2022), the deployment of RE has grown, with the addition of more than 26 GW of renewables-based generation capacity over the past decade; solar energy has seen the largest expansion, and average annual investments in RE have surged from less than 0.5 billion USD in the 2000-2009 period to USD 5 billion in 2010-2020; and Central and Southern Africa possess abundant mineral resources crucial for the production of electric batteries, wind turbines, and other low-carbon technologies. A study by IRENA predicts that about two-thirds of rural mini-grid and off-grid systems will rely on solar PV, small hydropower, and wind (IRENA, 2016).

2.1.1. Solar PV technology

Solar PV has the potential to supply electricity to more than 600 million people in Africa. Moreover, since 2012, the cost of utility-scale solar energy projects in Africa has decreased by 61%, bringing it down to less than USD 1.30 per watt. Presently, over 5 million African households rely on off-grid systems, including pay-as-you-go solutions (Diemuodeke et al., 2021, IEA, 2022). Consequently, the projected value of the off-grid solar market in Africa represents a significant yearly opportunity of \$24 billion (Hearon, 2022). According to IRENA's findings, PV is already the most cost-effective power source in many African regions. By 2030, it is anticipated that solar PV will outcompete all other power sources across the continent. When you consider the average practical yield of a utility-scale solar energy installation over the long term in each country, Africa leads with 4.51 kWh/kWp/day, surpassing Central & South America at 4.48 kWh/kWp/day, while North America lags at 4.37 kWh/kWp/day (IRENA and AfDB, 2022). To put these numbers in perspective, approximately 20% of the global population resides in 70 countries characterised by "excellent conditions" for solar power, meaning they consistently generate over 4.5 kWh/kWp per day in the long run. On a regional scale, only African countries collectively exceed this threshold.

Much of this untapped potential exists in the less developed nations of Africa, offering a unique opportunity to deliver affordable, reliable, and sustainable electricity services to a significant portion of humanity where there is a pressing need for improved economic prospects and quality of life, as the source highlights. Solar PV technology is currently and will continue to be a crucial energy source for SSA due to its significant potential and the increasing traction it is gaining. The underlying reasons are outlined in Table 4.

Table 4: Merits of solar PV technology deployment in SSA

Abundant solar resource	Sub-Saharan Africa is blessed with abundant sunlight throughout the year, making solar PV an ideal energy source. Countries in the region receive high levels of solar irradiance, ensuring consistent energy production from solar panels.
Energy access	Many areas in SSA lack access to reliable electricity. Solar PV systems, especially off-grid and decentralised solutions, can provide electricity to remote and underserved communities, helping to bridge the energy access gap.

Rural electrification	Solar PV plays a crucial role in rural electrification efforts. Mini-grids and solar home systems enable rural areas to access electricity without the need for extensive grid infrastructure, which can be expensive and challenging to implement.
Reducing energy Poverty	Solar PV helps alleviate energy poverty by providing households and businesses with clean and affordable electricity. This has a positive impact on people's quality of life, education, healthcare, and economic opportunities.
Energy independence	Solar PV reduces dependence on imported fossil fuels, enhancing energy security. This is particularly important in SSA, where many countries rely on expensive fuel imports, leading to energy supply disruptions and price volatility.
Sustainable development	Solar PV aligns with sustainable development goals by reducing greenhouse gas emissions, improving air quality, and mitigating climate change. It also creates jobs in the local solar industry.
Cost reduction	The cost of solar PV technology has significantly decreased over the years, making it more affordable and accessible. This cost reduction is due to advancements in technology, increased manufacturing capacity, and economies of scale.
Investment opportunities	Solar PV projects in SSA attract investments from both domestic and international sources. This contributes to economic growth and infrastructure development.
Technology Transfer and Innovation	The adoption of solar PV technology fosters technology transfer, knowledge sharing, and innovation, promoting local expertise and capacity building.
Government support	Many governments in the region are implementing policies, incentives, and regulations to promote RE, including solar PV. These measures encourage private sector involvement and project development.

Despite these advantages, challenges such as financing, grid integration, and capacity building need to be addressed to maximise the potential of solar PV in SSA fully. Nevertheless, the region's solar resources and the growing commitment to solar PV is an integral part of the energy landscape, driving sustainable development and improving the lives of millions.

2.1.2. Wind energy technology

Wind energy plays a pivotal role in advancing the sustainable development agenda in SSA. Despite the substantial challenges posed by COVID-19, the region is poised to achieve economic growth ranging from 2.3 to 3.4% this year. To support and sustain this growth, the provision of clean, cost-effective, and dependable electricity generation is paramount. In this context, wind energy, in conjunction with solar power, is anticipated to play a significant role in fulfilling the region's energy requirements. Although wind turbines are still a relatively uncommon sight across Africa, the continent faces substantial energy demands alongside considerable wind energy potential. Recent studies have unveiled a staggering technical wind potential of nearly 180,000 TWh annually, a capacity that could meet the electricity needs of the entire continent 250 times over (Munyengeterwa and Whittaker, 2021).

It is worth noting that the practical or commercially viable wind potential would be lower due to various constraints. Nonetheless, approximately two-thirds of Africa's total wind potential is situated in areas characterized by average wind speeds exceeding 7.5 meters per second (m/s). Some the countries with high wind energy potential are Mozambique, South Africa, Somalia, Madagascar, Morocco Lesotho, Malawi, Zambia, Eritrea, Djibouti, Ethiopia, Kenya, Tanzania, Niger, Chad, and Sudan (Alemzero et al., 2021, Elsner, 2019, Mentis et al., 2015). The development of wind energy in SSA holds the potential to make a substantial contribution to the region's sustainable growth trajectory while simultaneously addressing its escalating energy requirements. It presents an opportunity for clean and renewable electricity generation, reducing the region's dependence on fossil fuels and championing environmental sustainability. Wind energy in SSA is emerging as a promising and increasingly important component of the region's energy landscape because of the merits presented in Table 5.

Table 5: Merits of wind energy technology deployment in SSA

Abundant wind resources	Sub-Saharan Africa boasts substantial wind resources, particularly in coastal areas and high-altitude regions. These regions experience consistent wind patterns, making them suitable for wind energy generation
Energy diversification	Wind energy contributes to diversifying the energy mix in SSA, reducing dependence on fossil fuels. This diversification enhances energy security and mitigates the risks associated with fuel price fluctuations and supply disruptions
RE expansion	Many countries in SSA are actively promoting RE, including wind power, as part of their energy transition strategies. This supports global efforts to combat climate change and reduce greenhouse gas emissions
Rural electrification	Wind energy projects, such as wind farms and small-scale wind turbines, play a crucial role in rural electrification. They provide clean and reliable electricity to remote and off-grid communities, improving their quality of life and economic prospects.
Large-scale projects	Several countries in the region are investing in large-scale wind energy projects, including onshore and offshore wind farms. These projects have the potential to generate significant amounts of electricity for both domestic consumption and export
Job Creation	The development and operation of wind energy projects create jobs in construction, maintenance, and the supply chain, contributing to local economic development.
Investment opportunities	Sub-Saharan Africa has become an attractive destination for wind energy investments. International and domestic investors are showing interest in financing wind projects, bringing capital and expertise to the region
Grid integration	Integrating wind energy into the existing grid infrastructure can be challenging due to variability in wind resources. However, advancements in grid management and energy storage technologies are addressing these challenges

Environmental benefits	Wind energy produces electricity without emitting greenhouse gases or air pollutants, contributing to improved air quality and reduced environmental impact.
Capacity building	Developing wind energy projects necessitates capacity building and knowledge transfer. Governments and organizations are working to train local professionals and promote technology transfer.
Policy support	Governments are implementing policies, regulations, and incentives to encourage wind energy development. Feed-in tariffs, power purchase agreements, and tax incentives are commonly used to attract investment

Despite the significant potential of wind energy in SAA, there are challenges, including financing constraints, grid integration issues, and the need for regulatory reforms. However, as technology advances and more countries commit to RE, wind power is poised to play a substantial role in meeting the region's growing energy demand and supporting sustainable development (Boadu and Otoo, 2024, Gorayeb et al., 2024, Roga et al., 2022).

2.1.3. Small-scale hydropower

Small-scale hydropower plays a pivotal role in fostering sustainable development within SSA. It holds the promise of making a substantial contribution to addressing the pressing issue of rural electricity shortages in the region. Small hydropower, regarded as a promising decentralized electricity generation system for rural areas in SSA, offers numerous advantages, including adaptability, minimal initial investment requirements, and its status as a RE source (Kaunda et al., 2012). The significance of RE sources, such as small hydropower, in the context of sustainable power generation, has been extensively discussed, particularly regarding their potential to help meet the escalating energy demands within the region (Zeleeuw et al., 2022, Bamisile et al., 2023). Small-scale hydropower can generate sustainable and cost-effective electricity in the rural areas of SSA. It holds the potential to enhance living conditions, boost productivity, stimulate economic growth, and significantly improve the overall quality of life for millions of people in the region. The implementation of decentralised small-scale hydropower systems can offer an efficient solution for dependable and affordable rural electrification (Dagnachew et al., 2017, Ajewole et al., 2020). Small hydropower projects in the region are gaining attention as a sustainable and reliable source of electricity. Some of the key points about small hydropower in the region are presented in Table 6.

Table 6: Merits of small hydropower technology deployment in SSA

Abundant water resources	Sub-Saharan Africa is endowed with numerous rivers and water bodies, providing ample potential for small hydropower development. These projects harness the energy from flowing water to generate electricity.
Rural electrification	Small hydropower projects are particularly well-suited for rural electrification in areas that are not connected to the main power grid. They bring clean and consistent electricity to remote communities, improving living standards and economic opportunities.
Off-grid Solutions	Many small hydropower projects operate off-grid, reducing the need for extensive transmission and distribution infrastructure, which can be expensive and challenging to implement in remote areas.

Environmental impact	Compared to large-scale hydropower projects, small hydropower projects have a lower environmental footprint. They typically have less impact on local ecosystems and fish habitats.
RE growth	As part of the global shift towards RE, small hydropower is contributing to diversifying the energy mix in SSA, reducing reliance on fossil fuels and mitigating climate change.
Local economic development	The construction and operation of small hydropower projects create job opportunities in nearby communities, fostering local economic development.

2.1.4. Geothermal energy technology deployment in SSA

Geothermal energy represents a sustainable and environmentally friendly source of both heat and power, offering a valuable avenue for reducing carbon emissions in the electricity grid and the building sector. In the context of SSA, the region possesses substantial geothermal potential, particularly in the East African Rift System. The region holds over 15,000 MW, an estimated geothermal resource and the technology presents a spectrum opportunity (IEA, 2011). Geothermal energy has the potential to supply dependable and cost-effective electricity and heating solutions for both rural and urban communities, while also serving industrial and agricultural needs (Mulopo, 2022, Energy.gov, 2020). Furthermore, geothermal energy can play a pivotal role in fostering social and economic development, generating employment opportunities, and reducing greenhouse gas emissions (Energy.gov, 2023).

Geothermal energy in Sub-Saharan Africa is a promising and relatively untapped RE source. The United States Department of Energy (DOE) is actively supporting the deployment of geothermal energy in SSA through a range of initiatives. These initiatives encompass funding for community-based geothermal heating and cooling systems, as well as the provision of technical assistance and training (Cariaga, 2023). Some key information about geothermal energy in the region is presented in Table 7.

Table 7: Important information about Geothermal energy technology in SSA

Benefits	
Geothermal potential	Sub-Saharan Africa has significant geothermal potential, particularly along the East African Rift System, which runs through countries like Kenya, Ethiopia, and Tanzania. This region is characterized by geological activity, including volcanic activity and geothermal hotspots
Clean and sustainable	Geothermal energy is a clean and sustainable source of electricity. It produces minimal greenhouse gas emissions and has a low environmental impact compared to fossil fuels.
Base load power	Geothermal power plants can provide reliable baseload power, meaning they can operate continuously, providing a stable source of electricity. This makes them suitable for meeting the region's growing energy demand.
Reduced dependence on fossil fuels	Developing geothermal resources can reduce SSA's dependence on imported fossil fuels, enhancing energy security and reducing exposure to fuel price volatility

Rural electrification	Geothermal projects can be used for rural electrification in remote areas that are not connected to the main grid. This helps improve access to electricity and supports economic development in these regions.
Energy Access	Geothermal energy can help improve energy access and reduce energy poverty in Sub-Saharan Africa by providing affordable and reliable electricity to underserved communities.
Steps to fast-track geothermal energy technology development in SSA	
Investment and funding	Geothermal projects often require substantial upfront investments. International organizations, development banks, and public-private partnerships can play a significant role in financing these projects.
Technical challenges	Developing geothermal projects can be technically challenging due to the need for drilling deep wells and managing subsurface reservoirs. However, advancements in drilling technology are making these challenges more manageable.
Regulatory framework	Establishing clear regulatory frameworks and policies that support geothermal development is crucial. Governments need to provide incentives, such as feed-in tariffs and permits, to attract investment.
Local capacity building	Developing and maintaining geothermal projects requires skilled professionals. Efforts to build local capacity and train a workforce in geothermal technology are essential.
Environmental and social considerations	Like all energy projects, geothermal developments must consider environmental and social impacts. Proper assessments and mitigation strategies are necessary to minimize these effects.
Regional collaboration	Geothermal resources often cross national borders, so regional collaboration and agreements can be essential to maximize the utilization of shared geothermal reservoirs.

The development of geothermal energy in SSA faces various hurdles encompassing technical, financial, institutional, and environmental aspects. These obstacles include a lack of essential data, expertise, infrastructure, financial resources, regulatory frameworks, and public awareness (Energy.gov, 2023). Overcoming these challenges will require supportive policies, the enhancement of regional cooperation, increased capacity building, the mobilization of investments, and active engagement with stakeholders.

2.2. Green mineral deposits in Africa's renewable energy development

The transition to cleaner energy to stimulate economic growth entails the adoption of emission-reducing technologies, such as wind and solar energy, while minimizing reliance on fossil fuel-based technologies. While discussions on clean energy and the decarbonization of global investments and financial systems have been prevalent in development dialogues, there is comparatively less focus on the essential minerals, including rare earth minerals, metals, and construction materials, that are crucial for enabling this transition. According to data from the United States Geological Survey (USGS) regarding global mineral reserves (Ahadjie et al., 2023), Africa hosts a substantial share of various minerals, such as Cobalt (52.4%), which is crucial for various applications. Additionally, Africa possesses substantial reserves of Bauxite, essential for

Aluminium production (24.7%), Graphite (21.2%), Manganese (46%), and Vanadium (16%). This representation, however, only scratches the surface because ongoing exploration efforts in Africa are uncovering vast strategic mineral deposits. To highlight the significance of this, consider the example of cobalt.

These minerals are indispensable for the energy transition, as they serve as critical raw materials for the manufacturing of batteries and Electric Vehicles (EVs). Africa possesses substantial reserves of green minerals vital for the energy transition; however, it presently operates primarily in the early stages of the battery and electric vehicle supply chain. Mineral deposits are expected to play a crucial role in RE development in SSA in the following ways presented in Table 8.

Table 8: The crucial roles mineral deposits play in RE development SSA

Rare earth elements for clean technologies	Rare earth elements (REEs), which include metals like neodymium, dysprosium, and terbium, are essential to produce permanent magnets used in wind turbines and electric vehicle motors. Sub-Saharan Africa is rich in some of these elements, and their extraction is vital for the development and maintenance of RE infrastructure
Cobalt for batteries	As previously mentioned, cobalt is a key component of lithium-ion batteries used in electric vehicles and energy storage systems. The DRC plays a significant role in cobalt production, making it a crucial player in the supply chain for RE technologies
Minerals for solar panels	The production of solar panels relies on minerals like silicon, which is abundant in SSA. Silicon-based PV cells are the most common type of solar panels used globally, and having access to these raw materials is vital for expanding solar energy capacity.
Copper for electrical infrastructure	Copper is a fundamental element in electrical wiring and infrastructure. It is essential for transmitting electricity from RE sources to homes and industries. Several SSA countries, such as Zambia and the Democratic Republic of Congo, are major copper producers.
Geothermal resources	In regions with geothermal energy potential, such as the East African Rift Valley, minerals like silica are necessary for drilling and maintaining geothermal wells, which provide a stable source of clean energy.
Minerals for energy storage	Beyond cobalt, other minerals like lithium, nickel, and manganese are essential for energy storage solutions, including advanced battery technologies that can store RE for later use or grid stabilization.
Construction Materials	The development of RE infrastructure requires massive amounts of concrete, steel, and other construction materials, which are often derived from mineral resources like limestone and iron ore, both of which are found in SSA.
Job creation and economic growth	The extraction and processing of these minerals for RE projects can stimulate economic growth and job creation in the region, offering opportunities for local communities and governments to benefit from the RE sector.

Energy access and grid stability	Access to minerals enables the development of a more reliable and resilient energy grid, helping to provide stable access to electricity for households and industries, thereby improving the overall quality of life.
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The Democratic Republic of Congo (DRC) stands out as a prominent player in the energy transition industry, poised to reap significant economic rewards. This is because DRC accounts for a staggering 70% of global cobalt production and holds more than 51% of the world's cobalt reserves (AfDB, 2022). Many African nations, notably Zimbabwe, Namibia, Ghana, the DRC, and Mali, possess valuable lithium resources and the potential for lithium mining (Goodenough et al., 2021, UN-ECA, 2023). Nevertheless, there is limited involvement in the crucial stages further down the supply chain. At present, Africa lacks substantial capacity for processing lithium minerals, refining lithium chemicals, or manufacturing battery components. Africa should avoid a common scenario where mineral concentrates are exported, value is added outside of Africa, and products utilising lithium-ion batteries are subsequently imported.

The evident potential of Africa's lithium resources to make a substantial economic contribution should be viewed in the broader supply chain context. Specifically, the possibility of regional cooperation in the refining and production of lithium chemicals should be given serious consideration. However, it is important to note that while these mineral resources are essential for RE development, their extraction and processing can also present environmental and social challenges. Sustainable and responsible mining practices, along with proper environmental regulations and community engagement, are critical to ensure that the benefits of mineral resources are maximized while minimizing negative impacts.

3. The significance of renewable energy in SSA

Renewable energy is playing an increasingly vital role in SSA for several compelling reasons, primarily centred around electricity generation, especially from PV and wind power sources. These renewable sources are easily accessible, well-understood, and known for their swift and cost-effective deployment. Additionally, there are other crucial facets of the importance of RE in SSA, including (IEA, 2023b):

3.1. Enhancing energy accessibility

The inadequacy of power supply has been a significant impediment to socioeconomic progress in SSA, particularly in the face of growing industrialization, population expansion, and urbanization. The energy challenges are most severe in rural and remote areas of the Global South. The Global South must capitalize on the adaptable advantages of RE schemes in these areas to provide reliable, sufficient, clean, and affordable energy to underserved populations.

3.2. Decarbonisation and emission reduction

While fossil fuels, such as oil, natural gas, and coal have driven the economies of large and emerging nations, they have also brought about detrimental environmental and health consequences, including CO₂ emissions and the depletion of natural fossil resources (Ebhotu and Tabakov, 2018a, Ebhotu and Tabakov, 2019). The global call for a sustainable energy system that is secure, adequate, affordable, and environmentally friendly has become increasingly urgent (Harvey, 2014, Heffron et al., 2015). Expanding the use of renewable fuels can help mitigate or eliminate the adverse effects associated with fossil fuel consumption, given that economic growth relies on energy (UN, 2015). Furthermore, RE usage will prevent health

consequences - suffered by students caused by the use of kerosene lamps during the study; and women who use biomass for cooking, and their young children staying around them (Amegah and Jaakkola, 2016). These people are exposed to high levels of air pollutants, such as particulate matter (PM) and carbon monoxide (CO) emitted into the air (Amegah and Jaakkola, 2016, Ebhota and Tabakov, 2019).

3.3. Rapid construction

To address the pressing challenges related to fossil fuels, energy shortages, and climate change, SSA should leverage the rapid construction times of RE projects. Wind farms can be completed in 9 to 12 months, while solar parks can be operational within 3 to 6 months, a stark contrast to the years-long timeline required for fossil fuel plants.

3.4. Climate change mitigation

Human activities, such as fossil fuel extraction, consumption, cement production, and deforestation, continually influence the climate by releasing GHGs, such as CO₂, methane (CH₄), nitrous oxide (N₂O), and fluorinated gases. These gases account for global warming at different levels with CO₂ contributing the highest, between 75% - 80%, followed by CH₄ (14%), N₂O (8%), and fluorinated gases (1%) (IPCC, 2013). The energy sector, including fossil and biomass sources commonly used in SSA, accounts for a substantial share of CO₂ emissions. Shifting to RE helps to reduce GHG emissions, thereby mitigating the health, environmental, and climate impacts associated with these emissions. Governments of SSA countries should establish enabling policy frameworks to support adaptation efforts and harness local institutions and actors.

3.5. The declining cost of renewables

The lower cost of electricity production from solar PV and wind power, compared to fossil alternatives, serves as a pivotal motivation for embracing RE. This cost advantage is expected to widen further in the future due to the ongoing decline in RE costs. As a result, RE is poised to become a preferred choice over gas and coal power. Additionally, the increasing affordability of energy storage solutions, driven by falling battery prices, is anticipated to make a significant contribution to global power and heat consumption by 2050 (RES4Africa, 2023). Projections also suggest that global electricity production will transition to 100% renewable sources by 2050, with solar-based energy systems making up a substantial portion, particularly in Africa, where they are projected to account for over 80% of electricity consumption (Roodbol, 2019).

4. Sub-Saharan Africa's key renewable energy development limitations

It is imperative to analyse the constraints in energy generation and provision within SSA, considering the region's rapid population increase, economic progress, and escalating energy requirements. Africa's energy sector plays a pivotal role in the continent's economic potential, yet it has struggled to attain a dependable domestic energy supply essential for meeting the needs of its populace and enterprises. Sub-Saharan Africa faces several challenges in energy generation and supply, which have significant implications for economic growth, social development, and environmental sustainability. Some of the key energy limitations and issues of energy access in SSA are presented in Table 9.

Table 9: Key RE development limitations and challenges.

Limitations	Description
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High initial costs	The upfront capital costs of RE projects, such as solar PV installations or wind farms, can be substantial. This can deter investors and governments from pursuing RE initiatives, especially in resource-constrained environments.
Limited access to financing	A lack of access to affordable financing for RE projects is a major challenge. Many countries in SSA struggle to secure the necessary funds, both domestically and through international sources.
Grid integration	Integrating RE sources into existing electricity grids can be complex and costly. The intermittent nature of some renewables, like solar and wind, requires grid upgrades and energy storage solutions to maintain reliability.
Infrastructure and transmission challenges	Inadequate grid infrastructure and transmission lines in remote or rural areas can hinder the distribution of RE. Expanding and upgrading the grid to reach these regions is often expensive and logistically challenging.
Policy and regulatory frameworks	Inconsistent or outdated policies and regulations can create uncertainty for RE investors. Clear and supportive policies that promote RE development are crucial.
Resource variability	The availability of RE resources, such as sunlight and wind, can vary significantly across the region and throughout the year. This variability affects the reliability of RE generation.
Land use conflicts	Competition for land can arise when RE projects require large areas for solar panels, wind turbines, or bioenergy feedstock cultivation. This can lead to conflicts with agriculture and conservation interests.
Lack of local manufacturing	Relying on imported RE equipment and components can increase project costs. Developing local manufacturing capabilities can reduce costs and create jobs.
Access to technical support and expertise	Many countries lack the technical expertise and research institutions needed to support the development and deployment of RE technologies.
	Political Instability and Corruption: Political instability and corruption in some countries can pose risks to RE investments, discouraging foreign and domestic investors.
Lack of investment and financing	Insufficient investment in the energy sector hinders the development of new generation capacities and the expansion of energy access. Limited access to financing and high perceived risks deter private sector involvement (Appiah et al., 2023).
Transmission and distribution losses	Poorly maintained transmission and distribution networks lead to high energy losses during electricity transmission. These losses further strain the capacity of already limited power generation.

Climate vulnerability	Climate change impacts, such as droughts and water scarcity, can significantly affect hydropower generation, which is a common energy source in the region.
Regulatory challenges	Regulatory uncertainties can hinder long-term planning and investment in the energy sector.
Rural electrification	Extending energy access to rural and remote areas remains a challenge due to the high costs of infrastructure installation and maintenance.
Population growth and urbanisation	Rapid population growth and urbanisation in some parts of SSA are leading to increased energy demand, putting additional strain on energy resources.
Efficiency of electrical appliances	For instance, despite these gains, the demand for fans and air conditioning is projected to quadruple over the next decade due to urbanization and the effects of climate change, underscoring the need for a strong emphasis on efficient cooling solutions in Africa (IEA, 2022).
Political instability and corruption	Political instability and corruption in some countries pose risks to RE investments, discouraging foreign and domestic investors.
Environmental and social considerations	RE projects must consider potential environmental impacts, such as habitat disruption and water use. Additionally, community engagement and benefit-sharing mechanisms are important to address social concerns.
Intermittency and energy storage	Dealing with the intermittency of some RE sources, such as solar and wind, requires investment in energy storage solutions like batteries, which can be expensive.
Skills and capacity gaps	A lack of skilled personnel and technical expertise impedes the development, maintenance, and operation of RE infrastructure

Despite these challenges, there is growing recognition of the importance of RE in SSA for addressing energy access, reducing greenhouse gas emissions, and promoting sustainable development. Efforts are being made at the national and international levels to overcome these challenges through policy reforms, increased investment, capacity building, and technological innovation.

4.1. Strategies and approaches to address renewable energy development limitations

Despite the investments and the achievements recorded so far, relatively, the Global South, especially SSA, is grossly behind other regions: the RE investment and RE per capita of countries in Africa and that of the continent are far below other countries in other regions. The socioeconomic status of the people in SSA is yet to be substantially impacted by the efforts and investments in the RE sector. To reverse these trends, governments and international organizations should prioritise information-based electrification planning, mobilize capital, and deploy implementation programs, focusing particularly on countries and areas with very low access rates and those that have made only limited progress in recent years. It involves a

coordinated effort by the governments, private sector entities, development partners, and local communities. By overcoming these challenges, the region will unlock its energy potential and contribute to sustainable development and improved living standards. The strategies and approaches to address the identified RE development limitations and challenges are presented in Table 10.

Table 10: Strategies to address RE development limitations

Strategies	Description
Policy and regulatory reforms	Develop and implement clear and supportive policies, regulations, and incentives to encourage RE investments. Streamline permitting processes to reduce project development timelines and uncertainty.
Access to financing	Establish dedicated funds and financial mechanisms for RE projects, including grants, low-interest loans, and risk mitigation instruments. Attract private sector investment through innovative financing models, such as public-private partnerships (PPPs).
Capacity building	Invest in education and training programs to develop a skilled workforce in RE technologies and project management. Foster partnerships with universities, research institutions, and international organizations to provide technical support and knowledge transfer.
Grid integration and infrastructure development	Upgrade and expand the electricity grid to accommodate RE sources and improve grid reliability. Invest in energy storage solutions, such as batteries and pumped hydro, to manage the intermittent nature of renewables.
Local manufacturing and supply chains	Promote local manufacturing of RE equipment and components to reduce costs and create jobs. Support the development of regional supply chains for renewable technologies.
Community engagement and benefit sharing	Involve local communities in the planning and decision-making processes for RE projects. Implement benefit-sharing mechanisms that ensure local communities reap the economic and social benefits of projects
Environmental and social impact assessment	Conduct thorough environmental and social impact assessments (ESIAs) before initiating RE projects to address potential environmental and social concerns. Implement mitigation measures and monitoring to minimize negative impacts.
Resource assessment and planning	Conduct detailed resource assessments to identify the most suitable locations for RE projects. Develop integrated energy plans that incorporate renewables into the national energy mix.
Political stability and risk mitigation	Work on improving political stability and governance to reduce investment risks. Consider the use of political risk insurance and other risk mitigation tools to protect investors.
International collaboration:	Collaborate with international organizations, donors, and development partners to access technical expertise, funding, and knowledge sharing.

	Participate in regional energy initiatives to promote cross-border cooperation and energy trade.
Public awareness and advocacy	Raise public awareness about the benefits of RE and the need for sustainable energy solutions. Encourage advocacy and engagement by civil society and non-governmental organizations (NGOs) to support RE policies and projects.
Innovation and research	Invest in research and development to promote innovation in RE technologies, energy efficiency, and grid management. Support pilot projects and demonstration programs to test new technologies and approaches.
Market development and scaling up	Foster the development of RE markets through market incentives, feed-in tariffs, and power purchase agreements (PPAs). Encourage the participation of independent power producers (IPPs) and smaller-scale RE projects.

Addressing the challenges of RE development in Sub-Saharan Africa requires a long-term commitment and collaboration among various stakeholders. Tailoring strategies to the specific needs and circumstances of each country or region is essential for success

4.1.1. National power grid expansion

According to IEA, the expansion of national power grids is the most economical and sensible choice for nearly 45% of those expected to gain access to electricity by 2030 (IEA, 2022). However, in rural areas, where more than 80% of the population lacks electricity, mini-grids and independent systems, primarily solar-powered, emerge as the most feasible solutions. In this scenario, enhanced and upgraded electrical grids could form the fundamental infrastructure for Africa's evolving energy systems, with a growing emphasis on RE sources. Africa boasts 60% of the world's most abundant solar resources, yet it currently utilizes only 1% of its solar PV capacity (IRENA, 2016). Solar power, already the most cost-effective energy source in many African regions, is poised to surpass all other sources across the continent by 2030 (IEA, 2022). In the Sustainable Africa Scenario, renewables, including solar, wind, hydroelectric, and geothermal energy, contribute to over 80% of the new power generation capacity added by 2030.

4.1.2. Investment needs

Power shortages in SSA cost about 2% to 4% of annual GDP, and the way it is today, electricity will only improve to an appreciable level in the future. The electricity demand is expected to supply 2 billion people in SSA in 2050 and this requires a 3% yearly growth in the sector (Schwerhoff and Sy, 2020). Meeting this demand with the conventional energy mix of burning oil, coal, charcoal, wood, and dry dung fuel in the region would cause severe health and environmental consequences. In compliance with the 2015 Paris Agreement on the emission limits for GHG, therefore, there should be alternative sources of adequate energy. Fortunately, SSA is endowed with RE resources, huge enough to supply the needed energy to drive socioeconomic development. Studies have shown that a 100% RE system is possible for SSA (Barasa et al., 2018). Hence, the region does not need to rely on fossil fuels, and further investments in this conventional electricity should be avoided. What is needed is sufficient investments in the different RE technologies that have been identified across the region. The

present investment in RE by the region is relatively small considering the information in Figure 7 (IEA, 2023a), showing the annual clean energy investments in selected regions and countries between 2019 and 2023. Investing in RE energy will generate new job opportunities in the power sector and ensure sustainable development ecologically (IMF, 2019).

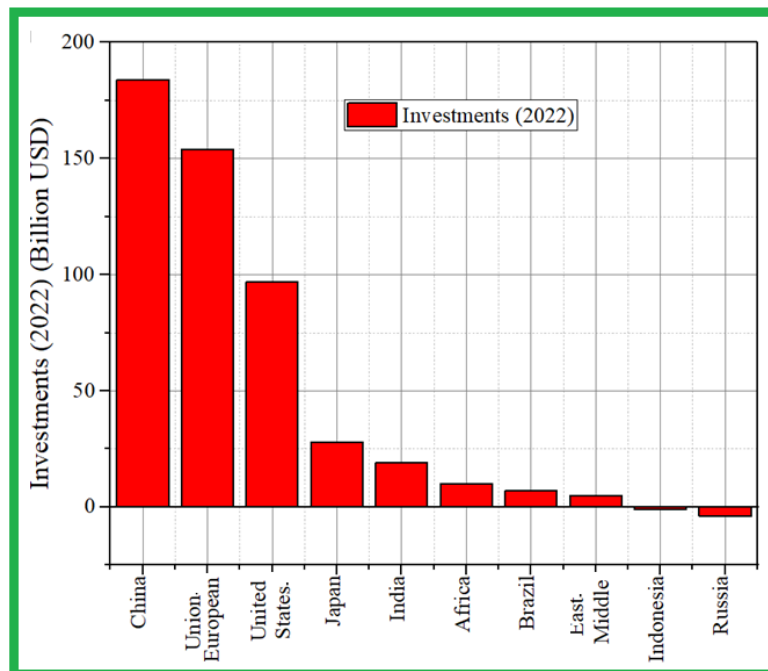


Figure 7: Annual clean energy investment in selected countries and regions, 2019-2023 (IEA, 2023a)

4.1.3. African Development Bank (AfDB) Intervention: The Sustainable Energy Fund for Africa (SEFA)

The African Development Bank (AfDB) recognises that modern energy services play a central role in sustaining inclusive growth, driving job creation, and enhancing productivity across various sectors such as manufacturing and agriculture. However, Africa has faced persistent challenges related to limited power access, frequent shortages, and high costs, hindering its socioeconomic progress (Ebhotu and Tabakov, 2018b). To address these issues, AfDB has implemented a range of initiatives aimed at improving energy accessibility and availability in Africa. These initiatives encompass various areas (AfDB, 2008), including rural electrification, efforts to combat deforestation, the development of decentralised energy solutions, and the promotion of sustainable biofuels. Additionally, AfDB has focused on enhancing energy efficiency in the transportation sector, transitioning to renewable and low-carbon energy sources, adopting clean technologies, and improving overall efficiency in the energy sector. Renewable energy has emerged as a critical solution for providing sustainable, affordable, and resilient energy access in SSA. Consequently, Africa has embraced RE as part of its long-term vision, including the vision to energise and light up African projects and the African Union's Agenda 2063 (AU, 2013, Worldbank, 2020b). This commitment has led to a significant acceleration in the deployment of RE technologies.

Adequate energy availability, affordability, reliability, and sustainability have been portrayed by the AfDB as fundamental factors driving the socio-economic transformation of Africa (AfDB, 2020). As part of its RE development programme, AfDB aims to support the continent in achieving universal electricity access by 2025 and is expected to yield specific outcomes. Taking the New Deal on Energy for Africa and AREF II as examples, the total investment cost for the

New Deal on Energy for Africa falls within the range of US \$60 billion to US \$90 billion annually. The anticipated results of this initiative include the expansion of grid power generation by 160 GW, connecting 130 million people to the electrical grid, connecting 75 million people to off-grid energy systems, and providing 150 million households with access to clean cooking energy (AfDB, 2019).

4.1.4. Political commitment and unpredictability

The insufficient political commitment demonstrated by governments in addressing the power-related issues in SSA, combined with the ongoing violence and crises in the region, have adverse effects on the development of RE. The myriad issues in the region, including but not limited to banditry, terrorism, communal conflicts, militancy, coup d'état, and youth unrest, tend to undermine development efforts across the board (Agwu et al., 2023). Political antagonism and instability act as counterproductive elements in the delivery of infrastructure projects, disrupting smooth transitions and advancements (de Bercegol and Monstadt, 2018). Regional leadership must collaborate closely with national governments to establish and maintain the peace and political stability necessary for nurturing and sustaining development.

4.1.5. Reviewing policies and institutional frameworks

A critical need exists to reassess the existing RE policies and frameworks in countries across the region, aligning them with contemporary political and economic dynamics to ensure that intended outcomes are achieved. The adoption of research-based policies can serve to harmonize the diverse perspectives of stakeholders, fostering robust and effective partnerships within the RE sector. Furthermore, addressing ambiguity within the management and regulatory processes is essential, with a focus on promoting transparency and professionalism within the sector.

4.1.6. Conducting feasibility studies and resource characterization

Renewable energy potential and the performance of RE systems inherently depend on specific locations or regions. To maintain the integrity of system performance and ensure optimal utilisation of RE resources, it is imperative to conduct assessments and characterise the potential of these resources. The region should take advantage of available econo-technical tools to evaluate the feasibility of these resources and integrate the findings into RE policies and frameworks.

4.1.7. Developing technical expertise

This study has identified a noteworthy gap in the promotion, development, and deployment of RE technologies in SSA, namely the absence of essential technical skills and the necessary manufacturing infrastructure. Notably, the USA and China have made significant strides in terms of installed RE capacities, largely attributed to their robust technical capabilities in personnel and manufacturing infrastructure. Currently, the region lacks both the technical workforce and the infrastructure required for the design, fabrication, operation, and maintenance of RE devices and systems within its borders (Ebhota and Inambao, 2016, Ebhota and Inambao, 2017). Consequently, both national and regional efforts must be deliberately directed towards building the requisite capacity within the RE sector.

5. Conclusion

Insufficient energy access poses a hindrance to the socio-economic advancement of the Global South, particularly SSA. The research assessed SSA's energy situation, its challenges, and the

potential of RE, along with discussing methods to enhance energy provision in the region. Sub-Saharan Africa stands as the world's least electrified area, with only 48% having access to electricity and a mere 17% enjoying clean cooking facilities. Notably, Nigeria (86 million), the Democratic Republic of the Congo (76 million), and Ethiopia (55 million) account for the largest populations lacking access. Several factors contribute to the electricity deficit, including inadequate infrastructure, prohibitive costs, and environmental repercussions. The region's electricity demand is influenced by a multitude of factors that mould the energy landscape of the region. The consequences of this energy deficit in SSA manifest as rising CO₂ emissions, deforestation, ecosystem disruption, health issues, climate change, loss of biodiversity, slowed economic growth, and deepening poverty levels.

Renewable energy is expected to assume a pivotal role in resolving energy access challenges, decarbonising energy systems, offering rapid deployment solutions, and mitigating climate change. It is becoming increasingly cost-competitive, thus paving the way for a sustainable energy future in the region. Africa boasts abundant RE resources, estimated to be approximately 1,000 times greater than the expected electricity demand by 2040. This surplus of RE potential, equivalent to 11,000 gigawatts (GW) of exploitable generating capacity, positions the continent favourably to meet its current and future energy needs. Key RE sources such as hydropower, solar PV, and wind energy dominate the landscape and offer decentralized and off-grid solutions, facilitating access to remote and underserved communities. The potential of solar, hydro, wind, and geothermal resources in Africa is estimated at 10 TW, 350 GW, 110 GW, and 15 GW, respectively.

However, several obstacles and challenges impede the development and widespread adoption of RE in the region. These obstacles encompass high initial costs, restricted access to financing, issues related to grid integration, infrastructure and transmission deficiencies, policy and regulatory frameworks, and the variability of RE resources. Additional challenges include conflicts over land use, the absence of local manufacturing capabilities, limited access to technical support and expertise, and a shortage of investment and financing. To surmount these hurdles, it is imperative to foster collaboration among governments, academic institutions, industry stakeholders, and international organizations. The study underscores the importance of addressing energy supply limitations through strategies, such as policy and regulatory reforms, enhanced access to financing, capacity building, and the development of grid infrastructure. Furthermore, strategies like bolstering local manufacturing and supply chains, engaging communities and sharing benefits, and conducting thorough environmental and social impact assessments are vital. The study portrays the energy deficit and RE potential in SSA as opportunities to transform the region into a hub for clean energy.

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