Sustainable Energy Transition in Sub-Saharan Africa

Charles Adulugba

Abstract There are little or no records of regions in Sub-Saharan Africa involved in key energy transition programs. Nearly all the countries in the sub-Saharan African region and developing countries rely on fossil fuels and low-efficiency hydro systems for energy generation. With a global shift towards more sustainable, cleaner, and renewable forms of energy generation, these countries must seek new ways to transition from their reliance on old methods to more modern and efficient means of energy generation. In addition, there is a severely negative impact from the generation of energy using these inefficient and environmentally harmful methods. The consequences are far-reaching as the health and economic life of the inhabitants of the region are negatively affected. Furthermore, the theft and vandalism of energy generation and transmission infrastructure and social insecurity in the region has led to very low efficiencies in capacity leading to huge wastes of natural and human resources. This chapter explores the feasibility and necessity of energy transition in the Sub-Saharan African region. It also analysis both the prospects and challenges that are faced by the people and the governments in the region while proffering solutions. Analysis of the situation is made through empirical evidence from studies and previous research works. The findings indicate that sustainable energy transition in Sub-Saharan Africa is achievable but is intricately woven with several pertinent environmental factors and that the general progress and development of nearly all facets of the environment relies heavily on the energy transition of the region which must be made timely.

Keywords Renewable energy · Energy transition · Sub-Saharan Africa · Carbon footprint · Energy crisis · Energy security · Electricity generation · Fossil fuel · Solar energy · Biomass

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M. Asif (ed.), *Energy and Environmental Security in Developing Countries*, Advanced Sciences and Technologies for Security Applications,
https://doi.org/10.1007/978-3-030-63654-8_8

1 Introduction

Forty-eight of Africa's fifty-four countries which make up Sub-Saharan Africa (SSA) is home to nearly 1 billion people, but it remains one of the poorest regions of the world as regards electricity. About 600 million people within the region currently lack access to electricity and 80% of those with electricity access are connected to unreliable grids that supply insufficient energy with negative economic and health implications [1]. The access rate to electricity of countries within the region is estimated to be a little above 40% with the annual average electricity consumption per capita recorded to be around 185 kilowatt-hours (kWh), which is about 15% when compared to the 3,000 kWh per capita global average. The total generation capacity of Africa as of 2018 was about 245 GW which compares to a quarter of the capacity installed in European countries. The picture is even worse as South Africa and North African countries, account for around 165 GW of this installed capacity [1], without accounting for other factors that reduce the overall capacity. The International Energy Agency (IEA) forecasts the total demand for electricity in Africa to increase at an average rate of 4% a year through 2040 but also projects that about half a billion people will still lack electricity access due to population growth. Full electricity access is expected to be achieved in 2080. Wealth inequality and the cost of available electricity makes electricity unaffordable even for some with access to the grid, this situation gives rise to other problems such as poor health, lack of proper educational facilities and, slow economic growth [1, 2]. There is also a lack of proper grid infrastructure and overdependence on fossil fuel which also has negative effects on the health of the people and the environment. Technical, financial, and policy issues also plague the energy sector of the region, but a proper collaboration of public-private partnerships can provide solutions to a smooth and successful energy transition for the region [3].

The problem of electricity in sub-Saharan Africa (SSA) is a complex one, the region is in desperate need of technological advancement and development, and this largely hinges on the availability of reliable energy [3]. With the present global push for net-zero emissions and cuts in carbon emission, most countries in the region find themselves caught in between the dilemma of either having to go after sufficient and reliable energy for their ever-increasing population or focusing on reducing emissions as a result of energy generation [1, 4, 5]. The temptation to ignore the negative impact of greenhouse gas emissions in pursuit of adequate electricity irrespective of the environmental impact is hard to overcome since leaders in the region have realized the link between energy and poverty alleviation. But the governments of sub-Saharan Africa do not have much of a choice since energy transition is inevitable with the current global push for clean energy and it guarantees sufficient, reliable, and sustainable energy. More so, there has not been any concrete proof that there is a relationship between poverty alleviation and the increase of CO_2 emissions—as some studies have suggested; although findings have shown that sustainable energy transition can reduce both poverty and the carbon footprint [6].

There is a huge energy crisis in SSA, and despite its renewable energy potential, a large portion of the funds invested in tackling the energy crisis has been used to procure alternative energy that is inefficient, expensive, and in most cases dangerous to the health of the people and the environment. From records of previous years, it can be deduced that at least 32 TWh Energy demand was met using backup generators in 2019 alone, but this has severe impacts on the environment and the health of the people of the region. The fast-growing population of SSA makes the energy situation even more difficult to solve as projections suggest the energy demand of the region will double by 2030 [7]. A radical and effective approach must be put in place to address all these issues by the regional governments with consideration for current global trends. If success will be recorded in transitioning to more reliable and clean energy from the current energy generation methods, renewable energy must play a very central role in the process.

With the population projected to increase in SSA between now and 2050, energy demand will implicitly increase in the region as well. The United Nations' goal of global electrification by 2030 means that at least 84 million people must be provided with electricity annually. This is a difficult task as currently, over 1.06 billion people in the world have no access to electricity with well over 630 million of that number living in SSA [8]. The situation gets more complex since most of the population of SSA reside in rural areas where access to grid electricity is absent, the most practical means of providing electricity to those areas will therefore be through stand-alone infrastructure. This again poses a new challenge as huge sums will be required to be invested to achieve this goal. Financial constraints have been one of the problems that have plagued the energy sector like many other sectors over the years and this problem has remained until now. Corruption, theft, and vandalism of energy assets have dealt huge blows to the successful achievement of adequate and reliable energy in the region. Among other technical and environmental factors, this social vice must be tackled as well to record a successful transition.

2 Energy and Environment in Sub-Saharan Africa

Sub-Saharan Africa is home to almost 50 developing countries, most of which struggle to provide enough energy that will lead to the development of their regions. With only 7 countries in the Sub-Saharan African (SSA) Region having over 50% access to electricity, the region is in dire need of a reliable energy supply but the conventional methods of energy generation and centralized grid systems cannot meet the required demand [7]. This has been the perennial pursuit for most of these countries and the problem has become more difficult to handle with the increasing population and subsequent increase in demand for electricity. The problem is not only about sufficient energy generation but also the efficiency of the methods of generation and transmission and consideration for the carbon footprints which most of these energy generation methods leave behind. Stakeholders, policymakers, and investors have unanimously agreed that they must take multiple pathways to solve the energy crisis and achieving the required energy goal of SSA. High level, transparent and detailed scenarios have been drawn up to present a clear picture to stakeholders of all the work that is required in the energy sector of SSA to meet the energy targets by 2030.

Statistical projections from experiments and forecasts have shown that installed generation capacity will grow up to 3 times by 2030, but analysts have suggested that at least 10 times the present generation will be needed to meet the required demand which represents a 13% annual growth rate [1, 9]. These figures seem discouraging, but they tell the disparate tale of the energy crises of the region. Foreign investors, private firms and, Public-Private Partnerships agreements will need to be made for this huge challenge to be conquered. The private sector is particularly key in this project as it has proven to be the best option for successful projects but with a daily per capita income of only about $2, most of the rural inhabitants of SSA are simply unable to contribute to this transition and have to continue relying on crude sources of energy such as coal fires and firewood. The government has to play a role in encouraging the involvement of the private sector. The cost of connection to the grid for a domestic home is around $400 which is largely beyond the reach of many homes in the rural communities; this is as a result of comparatively high costs of energy generation in SSA compared with other parts of the world. Southern African Power Pool (SAPP) was $72.3/MWh in 2016–2017 compared with NordPool, the largest electricity market in Europe, which was $34.6/MWh in 2017. This high cost is linked to many factors such as poor grid maintenance and operation, low efficiencies in energy generation and transmission, illegal connection and, electricity theft among many other factors [8].

Energy transition is essential not only in the sub-Saharan African region but globally, this transition is important especially at this helps in tackling the problems of global warming and to solve the climate change problem, and to guarantee energy security. Barasa [7] stated that energy generation accounts for over two-thirds of the anthropogenic greenhouse gas emissions, this figure may be higher in the sub-Saharan African region even though it is not as industrialized as some of the more advanced countries like China and the United States. The heavy dependence on fossils for energy generation with very little strides made in the area of Renewable Energy (RE) is responsible for this situation. Currently, IEA studies indicate that the combined generated energy from all RE schemes except for solar will reach 12GW by 2040 which will be only 15% of the total generated energy. 26% will be generated by hydro to make up for the 1540TWh projected and this indicates that SSA is projected to be about 60% dependent on fossil fuels even by 2050. The prospects for any region with this forecast are not promising as it suggests that a large portion of SSA will lack access to clean and reliable energy well into the future.

The quality of life and the level of the general development of the people within the region will improve as more of them begin to get access to reliable and sufficient energy. The governments in the region have not shown any real commitment to other forms of energy generation aside from fossil fuels. Biomass especially has been seen as a retrogressive source of energy and wrongly believed to be harmful to the environment hence there has not been any drive to improve energy generation from biomass. The governments in Africa need to realize, that biomass is capable of generating revenue flow from the urban to the rural areas, create employment, and increase the level of energy security of the region and not focus solely on foils for energy reliability and generation [1, 10]. At least 1000 TWh can be saved if the energy standards in the region become efficient and employ advanced technologies to improve industrial and commercial process heating, cooking, and air conditioning [7]. This is an area where biomass can play a very crucial role.

3 Feasibility of Energy Transition

Research has shown a huge energy potential in the region with several renewable sources, less than 10% of the hydroelectric potential has been harnessed, and not up 1% of its geothermal potential is currently used [11]. As of 2011, only 60 MW of the estimated geothermal capacity of 14,000 MW had been tapped [12]. The African Energy Policy Research Network has submitted that the electrical needs of the 16 southeastern countries in SSA can be met from agricultural waste in the form of biomass with bagasse-based cogeneration. Also, it has been estimated that South African coal power can be replaced by the use of hydroelectric from the Democratic Republic of the Congo which could cut down carbon dioxide emissions by up to 40 million tons annually [12]. 25% of Mauritius' energy is produced through the use of by-product cogeneration from the sugar industry, and it is projected to be capable of producing up to 13 times more with widespread rollout cogeneration technology and process optimization [11]. Karekezi, [13] as far back as 2003, outlined the potential of SSA as vast in energy production from fossils as well as RE sighting Africa's huge RE potentials especially in solar and bioenergy; but not much has been done since to harness it. The current electricity generation mix of the SSA region is shown in Fig. 1, as indicated, biomass, wind, and solar remain largely untapped, a successful

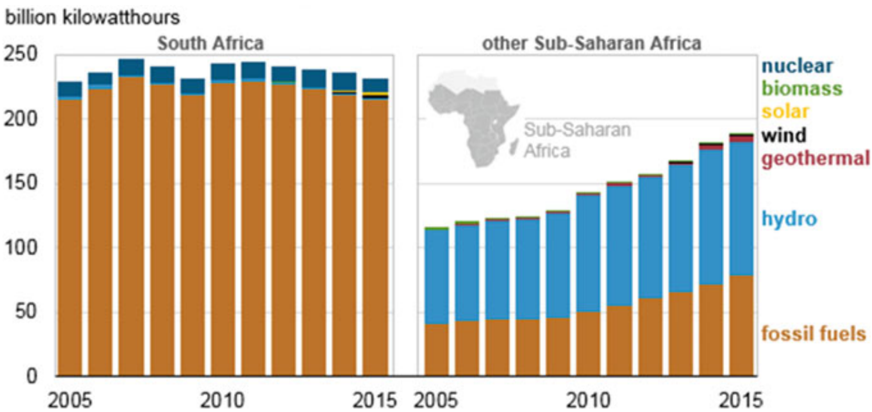

Fig. 1 Sub-Saharan Africa electricity generation mix (2005–2015) [36]

energy transition for the region will require the exploration of all possible energy generation methods.

The decision of the most viable RE resource in any given area is not always a very obvious one to make; extensive investigation needs to be done before selecting a renewable resource for energy generation. The cost of implementation and running the energy source, the pollution and disruption to the immediate environment, and the ability for the energy source to be expanded and relied upon are some areas that will determine the feasibility of any energy resource that will be used in energy transition [1, 5]. Some researchers suggested that renewable energy could as well be the least cost electricity solution for the sub-Saharan African region with studies indicating that RE is sufficient to cover 866.4 TWh estimated electricity demand by the year 2030, and solar PV and High Voltage Direct Current (HVDC) grids have been analyzed to be one of the most reliable sources [7]. Figure 2 shows PV as the most tapped RE resource followed by onshore wind and run-off hydro. While the best choice of RE to be used is determined by the actual geographical location in

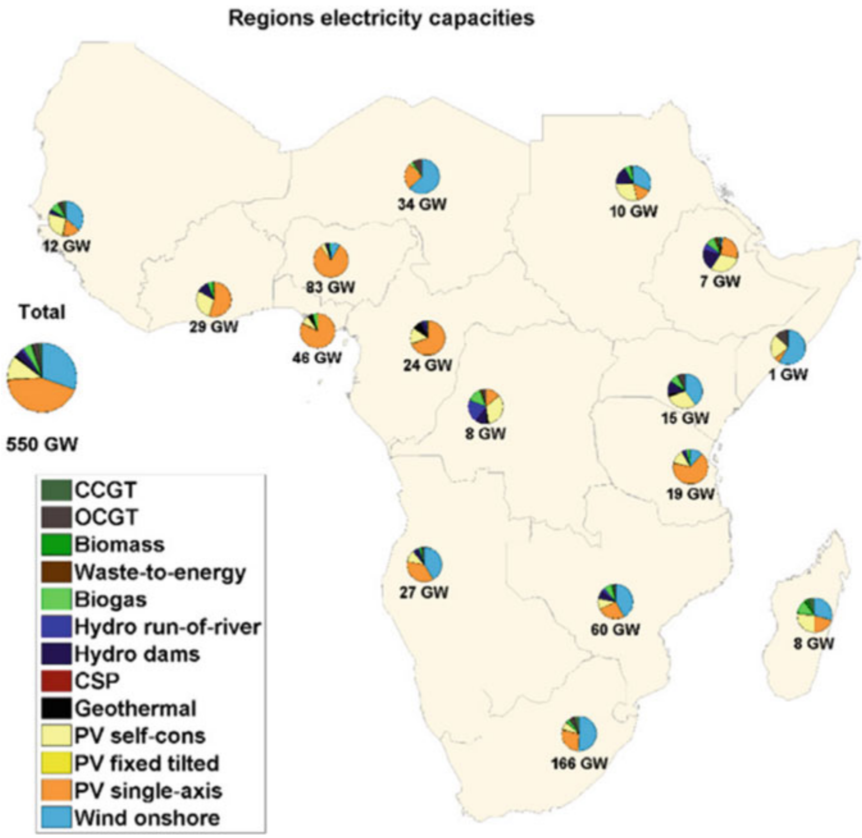

Fig. 2 Installed capacity of integrated RE schemes [7]

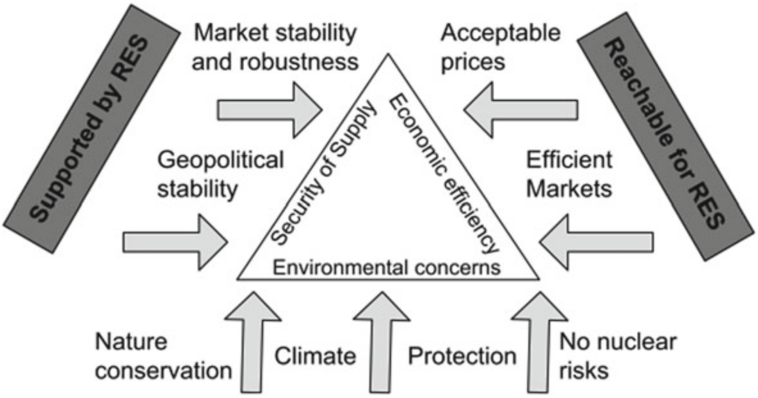

Fig. 3 Energy triangle showing the essential requirements for a sustainable energy supply system [5]

Africa, many other RE schemes can also be harnessed if properly investigated, and effective and innovative solutions employed.

There are large quantities of renewable energy sources in most of the African countries of sub-Saharan Africa [5, 7], solar, hydro, biomass, biogas, wind, tides and waves, hydrogen and geothermal being some of the most abundant renewable energy resources in the region. However, the integration of RE sources to the existing structure in the region for the expansion of energy is not always straight forward as many factors come into play to determine how well the system can perform. The market stability and robustness of the resource and the scheme, the availability of the resource, and the impact on the environment are some of the areas that will determine how well the RE scheme will perform. Figure 3 is an energy triangle that shows the essential requirements of a sustainable energy system, this model can be borrowed to investigate the most effective RE energy system for any particular are with SSA.

Energy transition can be approached in a flexible manner. Hybrid systems can be employed to complement each other depending on the season or the location in which they are installed and for the purposes for which the are intended. PV and wind energy have been seen to complement each other well, biomass can be integrated with hydro plants to boost the backup and installed capacity up to 15%. It has been predicted that one-third of the renewable energy required to meet 50% demand of SSA can come from hydropower while the remainder from solar PV, Concentrated Solar Plants (CSP) and, wind energy [7]. Renewable Energy systems can be set up using business models, most of the conventional models are too expensive for rural communities, Vanadzina [8] presents four solutions for rural electrification;

i. Nano-scale such as Solar Home Systems (SHS) with a capacity between 10–80 W, which basically are used for powering lights or/and small household appliances.

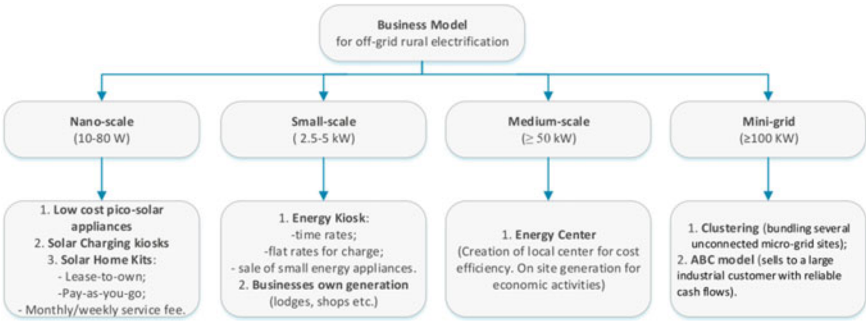

Fig. 4 Business model schematic for off-grid rural electrification in SSA [8]

ii. Micro-scale power installations which are intended to supply one entrepreneurial point or public institutions (such as school, police station, clinic, etc.) of up to 5 KW.
iii. Micro-scale power installations which are intended to supply one entrepreneurial point or public institutions (such as school, police station, clinic, etc.) of up to 5 KW.
iv. Mini-grid with capacity of more than 100 kW, consisting of a base station and distribution grid extensions to the consumers.

The business model in Fig. 4 presents an ideal approach for governments of the SSA region to use especially in tackling rural electrification.

These energy system models can be used as a means of predicting energy pathways for small households and large businesses, which will in turn help in the formulation of policies for the energy sector. Analysis of the energy demand of various settlements shows that urban households' energy consumption will increase significantly by 2050 and cooking is the most energy-intensive end-use. Transitioning from fuelwood to LPG cooking gas (Liquefied Petroleum Gas) for cooking increases CO_2 emissions but reduces the indoor pollution of the households. It has been seen that the energy models indicate that biogas and electricity are the more economically friendly option for cooking in SSA but more useful and effective policies need to ensure sustainable energy transition for the domestic energy sector [14].

3.1 Generation

Different approaches have been taken to propose the most feasible and cost-efficient generation strategies to meet the ever-growing energy needs on the African continent. There are several inefficiencies and losses in the energy system of the region and these losses are present not only at generation but also during transmission. The transitioning from fossil-based generation which is commonplace in SSA to cleaner and more efficient and sustainable methods is a task that currently burdens the governments of the region. Until recently, only hydropower had been explored as a renewable energy source. Fuelwood has only been used largely only for heating and cooking in rural areas, but no major strides have been taken in the processing and transitioning to biomass. Wind energy has not been harnessed as much as hydro and, solar; this is partly because the wind energy potential is not as promising and abundant as that of solar PV and hydro. Coastal countries in the north of Africa, South Africa, and a few countries in the east of Africa such as Ethiopia and Kenya where there is relatively good wind resource have seen relatively fair progress in wind generation [15].

3.1.1 Biomass

Biomass has always been accorded a low profile in energy policies SSA. There is clear prejudice and side-lining of the sector and this has translated to the apparent lack of support for biomass in the region. Generally, this trend could be said to have had negative effects on many countries in SSA which have not benefited as they could have from biomass. The focus has been on its eradication rather than its modernization to make it more efficient and robust. Policymakers erroneously due partly to not fully understanding biomass development have failed to provide policies to develop the sector, efforts should therefore be put in place to raise the awareness of the benefits of biomass and its prospects in order to support it so that maximum benefits could be derived from it [1, 10]. Research has shown that 1500 ha of land can grow energy crops to produce up to 20,000L of biodiesel per day and the Barrick Gold Mining Corporation (BGMC) a private company in Tanzania implemented this scheme [16], such schemes when implemented and supported by the governments of the region can dramatically transform the energy landscape of SSA.

SSA has been identified as having high potentials for the production of biomass since it has vast amounts of arable land and favourable climates. Krausmann [17] has submitted that at least 5% of agricultural land will be needed to meet 100% of RE. Land availability for sustainable biomass feedstocks is expected to shrink further with the growth of the population of SSA especially in the communities where biomass is largely used for cooking and heating. Also, substituting wood fuel biomass for electricity is not a straightforward approach as they meet different energy demands in the domestic space in the region. The ripple effects of industrial production of biomass could be felt in the reduction of farming lands and by extension food availability. Lands, which are unsuitable for farming, could be recovered to plant biomass feedstocks. This is a necessary approach as biomass remains a good alternative to fossils, but much planning must be done. Policies and legislation must be put in place to protect forests and vegetation and to encourage reforestation.

Biofuel initiatives have been implemented in SSA by private bodies and non-governmental organizations for the last 35 years. Almost all these initiatives are largely driven by foreign investors such as the Ethanol Company of Malawi. Projects conducted by multinational companies are being implemented to increase the production of biofuels in the region such as those in Tanzania but foreign investors only seek financial gains from the region due to the conducive environment for the energy crops such as sugarcane, sweet sorghum, and palm oil but show no substantial commitment to develop the region or improve the lives of the people. Many have called for the reduction or eradication of biomass because of negative and biased perceptions that it is inefficient and dirty. For example, Malawi seeks to reduce biomass energy consumption from 93% to 50% by 2020 while introducing nuclear power by 2050. Also, Tanzania's second National Strategy for Growth and Reduction of Poverty (2010–2015) endorsed a switch from wood fuel biomass to other energy sources such as electricity and doubled the access to "clean and affordable" substitutes [10].

3.1.2 PV

Photo Voltaic (PV) and Concentrated Solar Power (CSP) remain the dominant technology in SSA with a potential of generating up to 9261TWh and is projected to be capable of powering nearly 10 times the current electricity demand of the region. Studies have shown that it is also suited for the integration of desalination and gas sectors and for achieving 100% renewable energy in SSA [7]. PV has also been seen as one of the best options for powering domestic needs especially in rural areas where most of the population reside and where there is very little or no access to the grid network. Like all other renewable sources, PV has its own risks which over the years since it has been introduced in the region have been seen to be quite difficult to manage depending on its purpose or the area or location it is installed. The selection of sites for establishing solar PV plants has inherent site-specific risks and technical issues such as geotechnical, grid connection and, solar irradiation uncertainties. The Global Solar Irradiation (GHI) map in Fig. 5 for Sub-Sahara Africa shows that over 95% of locations within SSA receive at least 1826 kWh/m^2 annually which is encouraging for energy generation from solar.

Risks are more pronounced when government led panels design projects and select sites compared to private developer-led site selection [18]. There is also the ever-present danger of vandalization of installations and assets which has been prevalent in some parts of SSA such as Nigeria. These reasons are among some of the immediate factors and other associated factors that make investors sceptical about investing in PV energy in the sub-Saharan African region [18]. Notwithstanding, with proper focus on the optimization of PV installations and good site selection, the prospects of energy transition using PV in the region are high.

3.1.3 Hydro

With hydro energy schemes having longer life spans of about 40 years [7] compared to 20–25 years for PV, it remains one of the most attractive methods of energy generation in parts of SSA that have access to water resources. Central and southern Africa have one of the best hydro potentials in SSA with Congo DRC, Mozambique, Zambia, Cameroon, Ethiopia, Sudan, and Nigeria among the top [19]. Multiple rivers flow

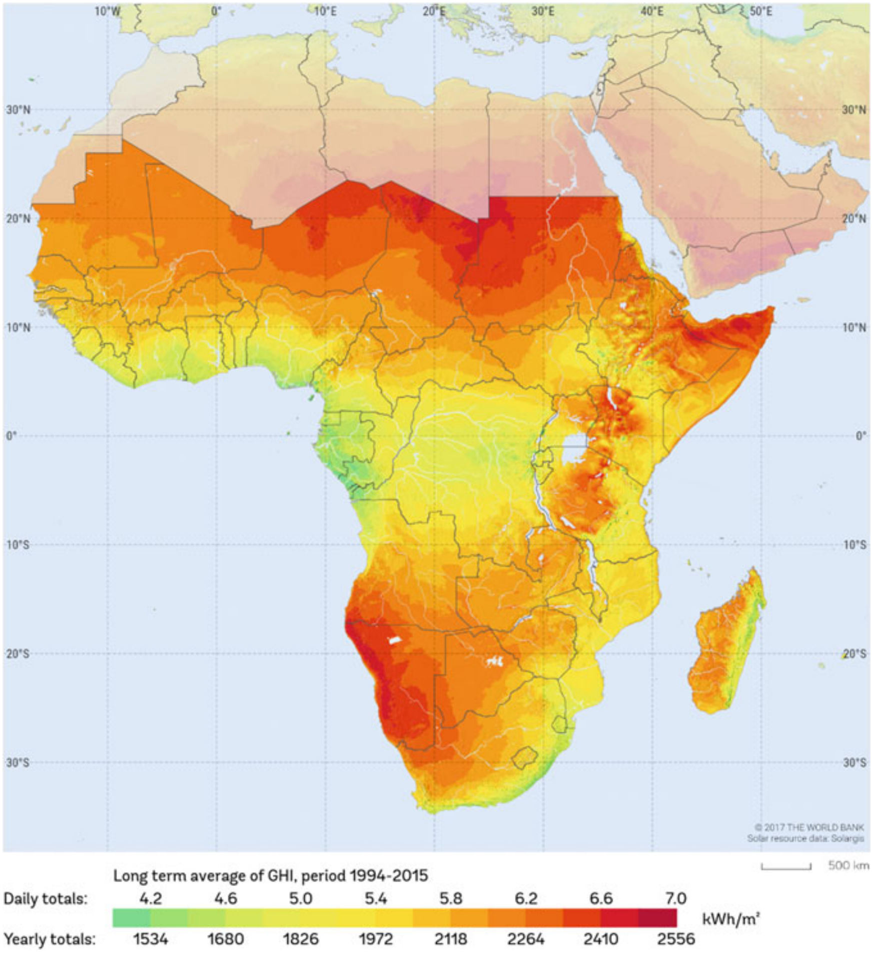

Fig. 5 Global solar irradiation (GHI) for Sub-Sahara Africa [37]

through central Africa which makes it have one of the best hydro-electric resource that could replace the use of coal which would ultimately cut down on the carbon dioxide emission levels [12].

3.1.4 Wind

Wind energy has not been as popular an option in Africa as Solar PV has been and has not been installed on large scales or for domestic dwellings as PV has. Africa has an average annual wind speed of at least 4 meters per second (m/s), which is less than the required minimum of 6 m/s needed for utility-scale wind power plants. This has made wind attractive only to coastal countries of Africa, South Africa, Ethiopia

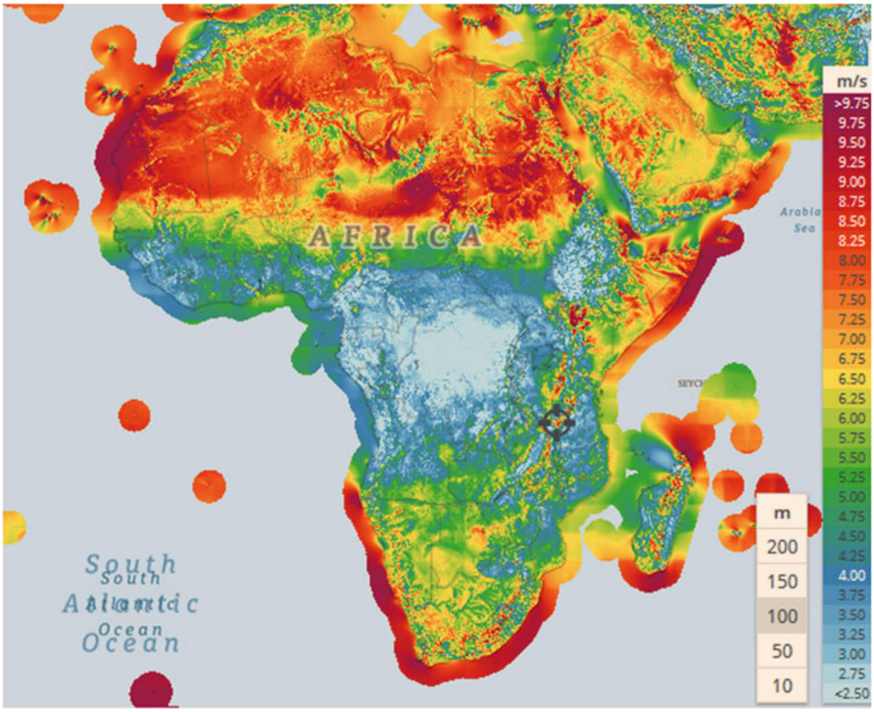

Fig. 6 Onshore wind speed for Sub-Sahara Africa [38]

and Kenya, and countries towards the north among the few countries in SSA that have installed wind generation capacity and are planning on expansion which could see an appreciable impact from wind energy by 2030 [15]. The input from wind may seem small but its contribution to the energy transition drive of Africa and SSA in particular, go a long way. Figure 6 shows some coastal countries in the south and countries in the north of SSA having average wind speeds of 8 m/s which is sufficient to generate electricity for the RE resource.

3.1.5 Geothermal

The geothermal potential in East Africa has given cause for the drive to harness geothermal power from the region, the arid climate makes this a preferred choice [20]. Countries within the central parts of the region and towards the west also have geothermal capacities but have not explored the sector and have not made sufficient investments in geothermal RE [7].

3.1.6 Hybrid and Decentralized Systems

There is currently no technical or cost analysis and financial breakdown of Hybrid mini-grids in SSA and this information is crucial to determine and overcome challenges in rural electrification planning, regulation, life-cycle operation, financing, and funding. This information on hybrid systems will help tremendously in the electrification of rural areas especially those without grid access, but where renewable energy sources abound. It is agreed that PV-hybrid mini-grids have the potential to provide energy for the rural population of SSA, but the pre-evaluation of the sector is lacking due to inadequate, unreliable, or unavailable information such as costs and performance of PV/hybrid. This has therefore kept stakeholders at bay as they remain uncertain about the outcomes of investing in the sector [21]. Notwithstanding, the overview of PV/hybrid mini-grids in Sub-Saharan Africa shows that renewable energy (RE) based mini-grid sector is growing slowly and beginning to attract the attention and interest of investors from both the public and private sectors.

The Africa Progress Panel has called for the diversification of energy generation through energy mix with a focus on off-grid systems with PV in the mix. There is also a push for the reduction of the costs for implementation of the system through replicable models which strengthen the SSA market and in turn reduces investment risks [21]. The present energy generation technologies can be applied in a decentralized way with the combination of energy efficiency measures for zero-emissions which will deliver low carbon energy systems. Produced energy from hybrid systems can be in form of heat and electricity which can supplement other forms of generated energy which could be from wind, biomass, and hydro. High efficiency generation using natural gas can also be employed in hybrid systems to supplement production to meet the required demand [22].

3.2 Transmission

Different schemes or methods in which generated electricity could be used to transmitted generated energy across the SSA. These include Regional-wide, where different sub-regions within SSA operate independently to generate and transmit required demand; Country-wide, where HVDC lines all lie within a countries borders; Area-wide, which requires sub-regions to be interconnected using HVDC lines, and an integrated scenario. The integrated scenario will make use of different technologies for generation and transmission and is expected to be more robust and flexible and to meet other demands apart from electricity demand such as industrial gas demand [7]. HVDC transmission is seen as the least cost solution to solving the transmission challenge of SSA by 2030 and the integration of water desalination and industrial gas sectors further reduces the overall costs [7]. Figure 7 shows the SSA Sub-region Transmission HVDC existing and planned line configuration which would facilitate the transmission of the generated energy across the whole region.

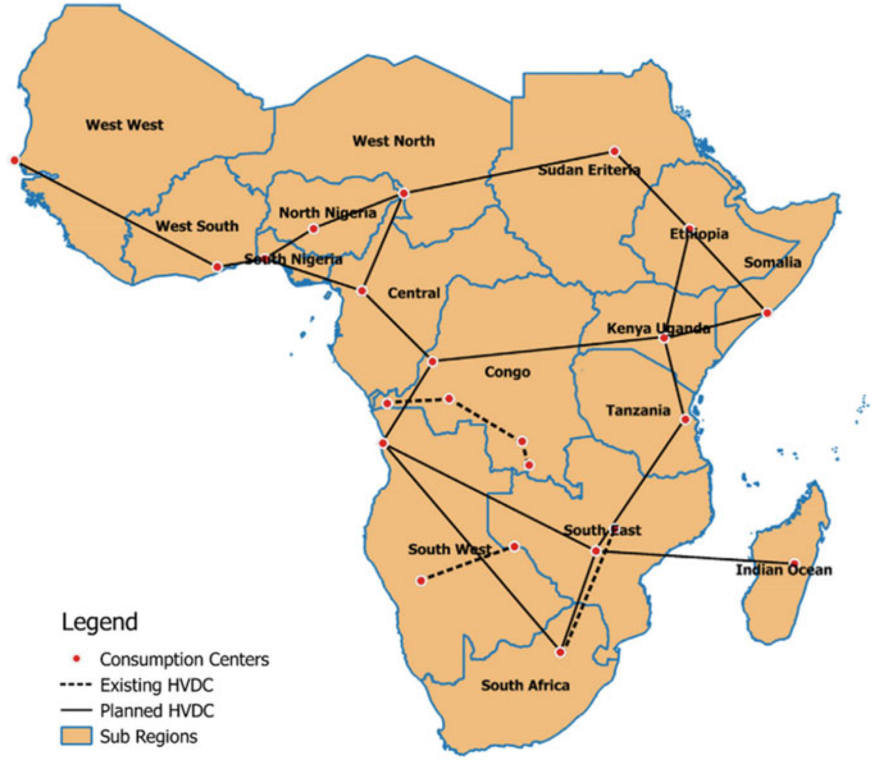

Fig. 7 SSA Sub-region transmission line configuration [7]

3.3 *Distribution*

Energy distribution in sub-Saharan Africa faces a fair share of challenge; distribution assets are regularly vandalized and key infrastructure stolen. Another major area of daunting challenge with distribution so far is with energy theft, meter bypass, illegal connections, failure of, and the inability of utility distribution companies to collect bills. This is aggravated by the fact that many homes in SSA are not properly marked and households are not clearly identifiable, making it increasingly difficult to bill residences for energy consumed. This situation puts a strain on the general system, and it creates a ripple effect as energy distribution utility companies fail to make required remittances to transmission companies which also can remit effectively to generating companies. A subsequent collapse of the entire system usually becomes inevitable if funds are not injected into the system.

This trend can be mitigated when micro-generation techniques are used as it will narrow the focus to the few homes connected to such systems which will make billing and metering much easier to operate and maintain.

4 Challenges of Energy Transition in the Sub-Saharan Africa Region

The lack of adequate infrastructure on ground in sub-Saharan Africa and the apparent lack of government commitment to energy transition are some of the challenges that energy transition will face. Other immediate challenges include limited capital investments, restricted power generation planning, and the lack of adequate skilled manpower for RE developments in the sector. This leads to increased cases of system failure and an unreliable system. Security and vandalism are also another challenge faced in the sub-Saharan African region, conflicts and wars in some parts of Africa have led to the crippling and in some cases, the total collapse of the grid system. The financial implication for transitioning to more reliable, efficient, and safer methods of energy generation and consumption is also a major challenge for SSA as most of its inhabitants cannot afford electricity costs. New methods employed in energy transition will therefore need to be affordable by the common man [20].

4.1 Policies

Energy policies and strategy development are not always implemented due to inconsistencies in government activities in the region, also, not all the authorities in the region have come on board to implement and enact policies to solve the energy crises. Only 13 governments out of the 35 in SSA have set and met the strategic targets they set for themselves for more advanced fuels such as liquefied petroleum gas and natural gas. Despite this being a major energy sector in SSA that must be considered in any development strategy, only seven have moved to improve wood and charcoal stoves [10]. It has been noted that many of the governments do not have any regulatory frameworks which make it difficult to follow any set of rules and to achieve the energy goal of their countries. This has made some private firms take advantage of the opportunity to the detriment of the localities where they operate. They acquire large expanses of land in a rather uncontrolled manner for growing energy crops and other related activities at the expense of food crops and small-scale farmers.

Public-Private Partnership (PPP) can help fix this problem as they help to mobilize financial resources for development [16]. This set of stakeholders however also need the security and guarantee from government policies to protect their investments and ensure that policies are adhered strictly to. A survey showed that countries across Africa have failed to consider individual energy access as an essential part of their development strategy. There is also a call for transnational initiatives such as the Chad-Cameroon pipeline to aid and speed up the development of the energy sector of the region. The United State of America pledged $2 Billion in capacity-building projects, policy and regulatory development, public-private partnerships, and loan guarantees to leverage private investment in clean energy technologies. There is also an initiative in South Africa to connect 500 million people to modern energy by 2025, a few other countries in SSA have shown some level of commitment to energy transition by the policies they make, but much work is still to be done [20].

The policies as a matter of necessity need to focus on rural areas for innovative and conventional business models [8]. The governments need to seek ways to diversify the Renewable Energy they have and harness the potential across its vastly different climatic zones, and consideration must be given to electricity grids that span across countries for the stability of energy supply. As mentioned earlier, this calls for cross-boarder cooperation among countries within the region for projects such as the installation of large dams to cater to regions and not just countries. With Hydroelectric capacity expected to reach 93GW by 2040, clear and visionary policies must be put in place to help with the development of the project and guide the regulatory framework especially in the area of biofuels. The policies will spell out clearly where the government is to come in and how the efforts of both the government and the private sector can be assessed and monitored while maintaining the vision of the country or government of the region.

The positive impact of functional policies will attract foreign investors and international stakeholders and renew the interest of the private sector to invest in the energy sector [16]. Until now, policies if at all present, were not always very clear, for example, only Malawi, South Africa, and Nigeria having set out clear mandates for the consumption of ethanol. The regulatory bodies are usually absent or ineffective from the energy sector, and Europe, America, and other developed countries take advantage of the lack of proper policies in Africa to harness the biofuels. This leaves farmers and those in the rural areas disadvantaged us the opportunity to partake and joint businesses is taking away from them [16]. Public-Private partnership (PPP) is crucial if the energy sector of SSA must be developed and expanded. The governments of the region could give incentives and waivers to encourage participation and investments from the private and public sectors, Uganda has some incentives under which import duties on certain raw materials are refundable under value-added tax (VAT) and a duty drawback scheme [16].

4.2 Funding

The energy sector in SSA is heavily underfunded compared to other regions of the world. This, among other factors, is responsible for the poor electricity and energy situation in the 49 counties of the region. In 2014, SSA with an estimated 800 million people had a generation capacity of less than 92GW, whereas Spain with a population of 45 million had an installed capacity of about 106GW. Over half of SSA generation is in South Africa, 48 other countries share the rest and only 14 countries in the region have more generate more than 1GW. Per capita installed capacity is 44 MW per 1 million people, India is 192 MW per million people and China is 815 per million [23]. The African Development Bank has estimated that a universal access system for all 53 countries in Africa would cost US$547 billion total to implement by 2030, this will require a lot of commitment from the authorities of the region as it will require US$27 billion per year for the period. Currently, the investment in the energy sector is still very far from this amount, only about US$4 billion is currently been invested in the energy sector annually including contributions by China and India. Foreign direct investment in the sector is generally very low in Africa as it receives less than 2% of foreign investment from across the world [24]. The problem of funding is made worse by the high upfront cost of many RE schemes and limited water resources in some regions. It has been seen that the World Bank, governments, and private investors are more confident with investing in tested conventional technologies than innovative ones targeted at the grassroots where energy is desperately needed [25].

Privatization can lead to the generation of funds for the sector, but this will come with inherent risks. It is therefore necessary for policies implemented to check any cons that may arise from privatization of the sector. It is expected that privatization will lead to increased efficiency and reduce overheads spent by governments on the system, this has been seen in Namibia and South Africa where electrification grew by about 40% in 15 years [26]. The downside of privatization is that while it offers many advantages, it could also be faced with issues such as increased market prices. It could also lead to a profitable customer ignoring or avoiding to risk of expanding the service to cover the rural areas and poor customers. Extension of the grid and services may prove too expensive for private firms especially if they have to connect low population density areas. Privatization if not managed properly will negatively affect the poorest of society [24, 26].

Having a Business Model (BM) helps with attracting funding, a business model is important as it provides a clear structure for achieving goals in developing countries. A Tariff-based model does not always solve the problem of business models as it is too expensive for small local communities. These models should have provision for Pico solar and Solar Home Systems to help to provide low capacity supply to low power supply to rural homes. Low costs energy projects and microloans schemes for energy development should also be considered as they can affect the shape of the energy landscape. Conventional generation and transmission grids are very difficult to fund due to high investment costs [8], larger scaled projects come with associated risks and are quite expensive to set up with investors not always available. This must therefore be considered when drawing up a BM. Rural electrification can be funded based on the project size and projects can be classified according to scale; 10–80 W nano-scale power solution which are powering lights or/and household appliances, such as solar home systems (SHS); 5 KW micro-scale power installations which are intended to supply one entrepreneurial point or public institutions such as school, police stations, clinics among others; 30–50 kW medium-scale solution which can serve as an energy centre for communities; and 100 kW and higher mini-grid, consisting of a base station and distribution grid extensions to the consumers. Some of these projects, especially the nanoscale and microscale, can be funded using pay-as-you-go schemes since they are more affordable for rural communities. The vast opportunities in the SSA can attract businesses seeking to make guaranteed profits in the communities. Mini-grid projects always need the intervention of NGOs or financial institutions that are not seeking to make any financial gains [8].

Greenpeace International [22] has mentioned some types of risks that could affect projects in SSA. Regulatory Risks arise as a result of sudden and adverse changes to policy and breeches to already signed contracts. It is agreed that policy security is vital for the success of the investments while it is advised that diversification of the investments across geographical areas; technology and regulatory jurisdictions can help mitigate this risk. Construction risks increase with the type and complexity of the technology involved and the cost of delivering the project, this makes the more common RE technologies less risky due to the fact that they are simple to design and implement. The quality of material used for the project determines the level of risk that could arise. Financial risks also abound in SSA, the misappropriation of funds and loans, the risk of interest rate, volatility, and refinancing at less favourable terms all contribute to different types of financial risks operational risks such as reduced primary RE source which include wind, heat, and insolation can adversely affect the business case of the project. Failure of equipment also constitutes operational risks. Designing the system with the worst-case scenario of RE sources and the use of reliable and premium equipment could help mitigate this risk [22].

Independent Power Projects (IPPs) remain the main source of investment in the power sector and it continues to grow which is a good trend but there is still more than 50 percent investment from the public sector which has not improved over the years. Private and foreign investors especially Chinese investors remain the key players in the energy sector of SSA and this picture may remain the same in the near future [27]. Figure 8 shows that IPPs are however more attractive to investors in some countries than in others due to instability which can be as a result of a host of issues in certain parts of the continent. The returns on investment are also another factor that attracts independent projects. The lack of IPPs has made some of the countries either lose some of their generation capacity or add nothing at all [27].

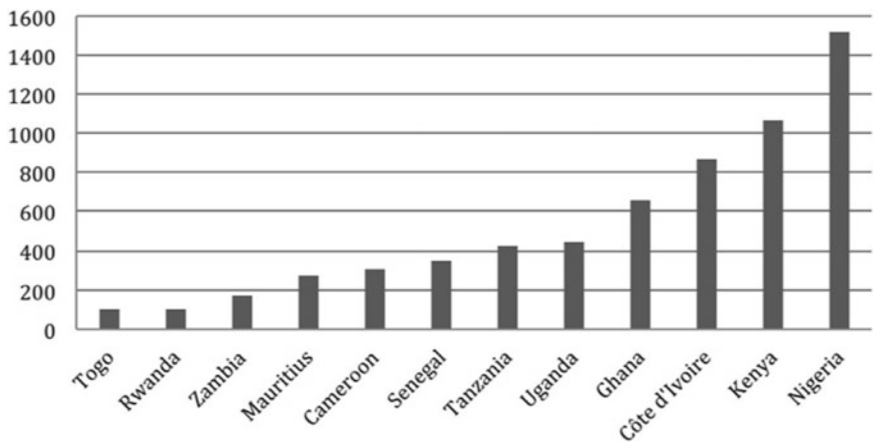

Fig. 8 Countries with the most independent power project capacity (MW) in Sub-Saharan Africa from 1994–2014 (excluding South Africa) [27]

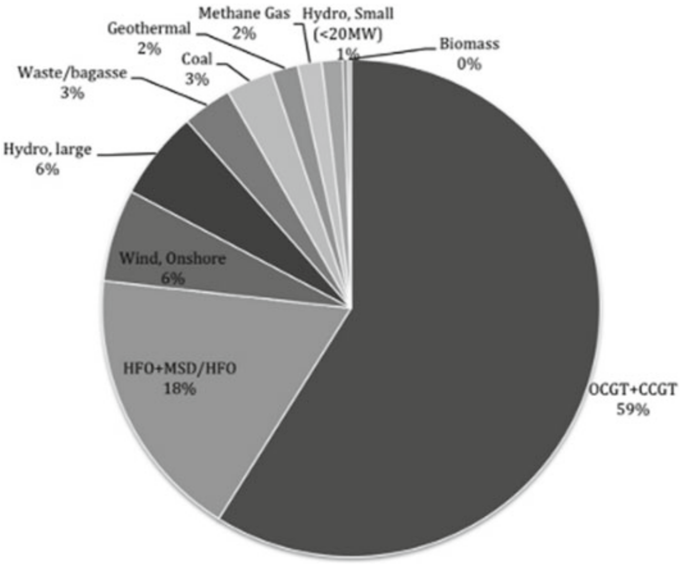

Fig. 9 Independent power project capacity (% of MW) by technology in SSA (excluding South Africa) from 1994–2014 [27]

Figure 9 shows an overview of IPP involvement in power generation in SSA and is quickly seen that over 75% of IPP involvement is in fossils through gas turbines and heavy fuel oils, their involvement in RE is still very little in the region.

IPP in SSA has a capacity of about 600 MW with over two-thirds of them less than 100 MW. Over 82% are thermal and combined-cycle gas turbines. There is growth in RE schemes run by IPPs in Africa but it is small with PV, CSP, and Wind as the main RE growth areas, state institutions such as Nigerian National Petroleum Corporation NNPC the Ugandan Government have invested in IPPs, but the prominent players remain the private sector. The success of IPPs is linked to factors such as power markets and independent regulation but utility companies are not always creditworthy as a result of the poor performance of the system and their inability to grow. The common model for power sector reform is to unbundle, privatize, and create regulatory institutions and markets; but this has not always worked as expected and has not always attracted investors as projected. IPP are left with different structures and no clear restructuring plan, they are however still very important for energy transition in SSA. Most countries in the region with IPP have independent regulators who create a competetive procurement atmosphere and provide oversight that is fair to all players. The failure of these regulations therefore has been a source of disincentives to investors, it is imperative that the regulators are transparent, fair, and accountable since regulation is crucial. The quality of regulation and not the presence of a regulator has been seen to be more important in SSA [27].

4.3 Social Challenges

It is debated that Sub-Sahara Africa has enough land to support farming to feed the population and to grow energy crops for biofuels on the vast underutized land which can be developed and reclaimed for useful purposes. The production of biofuels and biomass can help in poverty alleviation and help to boost the economy especially for rural dwellers in SSA [16]. PV has social impacts on the communities it is installed in, it also uses up land [18], land is a scarce commodity in some localities in SSA. The problem of insurgency and civil unrest in some countries such as Nigeria, Central Africa Republic, and Sudan has affected the investments and discouraged intending investors in the energy sector of SSA [28]. The use of bioenergy has caused negative impacts on the ecosystem, soil fertility, water resources, and forests which the livelihoods of the citizens in some of the localities where bioenergy is used. The quest for energy must therefore not create other hardships for communities where the systems are set up.

The use of lands for energy generation especially RE energy generation has the tendency to reduce the availability of the resource and this could affect the health of the people as a result of limited resources that could cause food shortages and may also lead to conflicts as land tussle is common in many regions of SSA. Bioenergy and energy transition must not create social inequalities and undermine food security all of which could be potential risks when using RE schemes. Priority must be given to communities where projects are located over the global or wider community. Energy transition needs to be resource-efficient and cut down to the minimum of greenhouse emissions, and this could be a challenge [22]. The health implication of the use of fuelwood and inefficient stoves cannot be ignored, as at least 79,000 deaths are recorded annually from pollutants and suffocation from these sources of energy.

It is seen that some cultural norms in some localities influence the choice of cooking fuels which impacts negatively in the long run on the environment. These communities need sensitization programs to help curb this negative trend, forests are being depleted and RE schemes could further impact this trend negatively. The poor economic state of the majority of the people forces them to continue using energy-inefficient electrical appliances such as air conditioners and cookers which have long served their useful life. Cheap inefficient filament light bulbs are still very rampant in many localities across SSA. As mentioned earlier, a serious campaign must also be raised to instill a good energy culture in the people. Traveling across SSA, it is common to see security lights left on even in the daytime. Burst water pipes and leaking taps are also quite common. This situation can be blamed partly on the inconsistency and epileptic nature of the electric sources which make people forget to turn off switches when they leave home during blackouts. A good energy culture will also inform people to cut down on energy use by reducing their extravagant and luxury lifestyles [14].

Corruption remains a worm in the social fabric of SSA. Investments have been made in the energy sector over the years with little or nothing to show. It is estimated that at least $45.6 billion dollars was invested in sub-Saharan Africa with the exception of South Africa between 1990 and 2013, but the current situation of the electricity in the SSA region certainly does not reconcile with this amount. It is reported also that an estimate of a least $490 billion will be needed in investments for additional power generation capacity by 2040 if the current energy demand of the region is to be met [27].

4.4 Technical Challenges

The lack of adequately skilled manpower to maintain and manage installations, especially the new technologies, could create a drawback for energy schemes to run smoothly, electricity is unreliable even in areas covered by the grid network and this affects the generality of the population including industries [26]. The incessant power outages lead to damages of equipment and discourage investors who seek to build factories in the region [29]. SSA also faces the problem of illegal connections which causes technical problems for the overall system. Theft of installed assets resulted in over 80 power failures in Tanzania, Uganda, and Kenya. That figure is much higher for bigger and more complex countries like Nigeria [8].

Transportation is an important element for the deployment and establishment of energy generating schemes around the continent. This raises another challenge—as many countries are land-locked and the transportation network is poor in the region [19].

4.5 RE Resource Availability and Environmental Impacts

Water footprints and displacements impact on the local populace, there is already a shortage of water in some parts of SSA, poor rainfall in some parts of the continent have led to a reduction in hydroelectric outputs. Forest degradation and dessert encroachment are now issues of concern and have prompted agencies such as USAID to contribute to improve forest governance and reduce the rate of forest degradation and loss of biodiversity through protected area management, improved logging policies with the aim to achieve sustainable forest use by local inhabitants [30]. Forests and wildlife need to be protected but currently, they seem to be getting depleted faster than they are regenerated. Trees unnecessarily cut or harvested for bioenergy must be replaced to help combat climate change and environmental impacts and reduce the carbon footprint [22].

The shortage of land has led to bloody communal clashes and land tussle which has affected food production. The seven Sustainable Development Goals (SDG) seek to address some of the environmental challenges that affect RE resources availability by 2030 and some countries such as Nigeria have shown a level of commitment to the realization of the goals [14].

5 Benefits of Energy Transition in Sub-Saharan Africa

The SSA region will benefit from energy transition and consequently, the effects will be felt in the environments of the region since renewable energy remains the topmost resource to replace fossil fuels which Africa is blessed with an abundance of. The inexhaustive nature of RE makes it an important part of energy transition. Due to the vast amounts of land that need to be covered by the electricity Grid, many rural communities remain isolated from the electricity Grid. To eliminate energy poverty and cut down carbon footprints in the process of providing energy to these remote areas and in some cases densely populated areas, the use of RE technologies must be heavily employed [5]. RE benefits will lead to developments of the rural areas of the sub-Saharan African region and remote areas especially stand to benefit [7]. The current methods of energy generation depend largely on fossil energy sources and RE integration can help reduce the dependency on fossils on the energy transition path.

5.1 Energy Security

With good solar irradiation prevalent in SSA, the prospects are very high and promising for energy generation through solar. The challenge of expensive transmission installations will be easily tackled for off-grid PV systems. The added advantage of this is that it also controls energy and asset theft and vandalism which is rampant in the region. Microgrids or SHS could solve the ugly situation of a very unreliable grid system and give the common masses access to reliable and affordable energy [8]. Diversity of generation will guarantee the availability of energy and energy security and also aid in energy transition as more efficient systems of energy generation will be employed There are prospects for development and technological advancement especially in combined heat and power CHP plants. This will also assist in climate change mitigation which countries all over the world are currently addressing.

Renewable energy sources will ensure flexibility of use, do not necessarily need to be processed or converted, and is readily available, it will also reduce the importation of electricity generating plants and benefit the region's land, climate, and labour. Modern sources of energy are properly processed before burning and have high efficiencies and clean combustion [10] which is beneficial to the environment and to human life.

5.2 Economy and Jobs Security

Job employment and energy security, around 350 jobs-days are created for every TJ of energy consumed as against only about 100 and 20 job-days created by electricity and LPG respectively. Energy transition will trigger investment in the energy sector which will in turn create new jobs and boost the economy. Economic benefits will include the production and transportation of densified fuelwood to different parts of the world; the production of biomass for export requires land, sunshine, and labour which are surplus in the region [10]. Visagie [31], noted that biodiesel technology if harnessed will create jobs for disadvantaged people in the rural areas of the continent while ensuring energy security and reducing greenhouse gas at the same time. Solar water heaters and biodiesel technology which were installed in South Africa significantly diminished poverty through job empowerment and helped improve the general wellbeing of the people in that vicinity [31]. It has been predicted that renewable energy jobs will account for 98% of jobs in the energy sector by 2030 with the non-biomass sector accounting for declines in biomass energy production [22].

5.3 Education and Health

Energy can facilitate the development of schools and enhance learning, it can also help teachers gain access to a wide variety of teaching mechanisms such as computers, and access to the internet. Energy can contribute to the allowance for freedom of education [32]. It will help to provide a comfortable environment required for effective learning to take place. Many school facilities lack basic amenities such as electricity and water which impact negatively on the learning of pupils. Furthermore, students cannot read when they are home after school as most of them who dwell in rural areas have no access to electricity and remain in darkness at night. Norway supported a program in Kenya to replace locally made kerosene lamps—which are dangerous and have negative health effects on people—with alternative solar power. One other key prospect for energy transition in sub-Saharan Africa is that it will help build healthy social connections between students and neighbouring communities.

Energy access reduces the time needed to process and cook meals at the family level where especially the girl child is usually burdened with cooking chores leaving her too exhausted to rest and study well. Gender inequality has been very bad in Africa where the women who are often overburdened with home chores have little or no time for self-development and empowerment. Energy transition will therefore help provide smarter and more efficient ways to quickly complete chores such and washing, cleaning, and food processing and have time for personal development and career pursuits. Food preservation will also be more efficient, as it reduces food wastage and food poisoning from poorly preserved food. Modern energy reduces the harmful emissions from crude cookstoves, ensures better indoor ventilation and air quality, and gives access to cleaner water. This in turn improves maternal health and reduces the risks around childbirths especially at night. Combating diseases is also enhanced by modern energy as nearly all laboratory work must be done using electricity [24].

5.4 *Transportation*

The automobile fleet in SSA is about the oldest in the world and more cars are expected to add to that number at a fast-growing rate due to the rapid population growth of SSA. This will lead to increased environmental pollution from the transport sector and an increase in transportation costs. It is seen that individual mobility will become more expensive forcing commuters to opt for smaller more efficient cars as energy demand from transportation is expected to rise by 170% to 10,400 PJ/a. Electric and Hybrid cars will therefore become the preferred and more economical option for transportation as has been demonstrated in most advanced countries in recent years. This trend is expected to keep getting popular and also become mainstream on the African continent. Hydrogen and fuels produced using renewable energy such as biodiesel will further increase the input of RE in transportation as it is projected that electricity will provide 3% of the energy demand of the transport sector by 2030 and up to 25% by 2050. This number could be up to 35% when advanced developments are involved [22].

5.5 *Environmental Sustainability*

Renewable Energy technologies reduce the energy demand and carbon footprint from energy consumption, especially in the residential sector. Environmental sustainability is a major concern for governments across the world today as it directly has health implications on humans. This understanding is therefore expected to inform the fuel choices that the governments of SSA [14]. Access to contemporary energy to create jobs and modernize the agricultural sector to eliminate hunger and poverty will have a positive impact on the environment as destructive techniques will no longer be employed. Energy transition can facilitate sustainable development and control the degradation of land resources. The direct link between charcoal production and desertification and deforestation is a testament to this fact [24].

6 The Future of Energy Transition

More counties in sub-Saharan Africa will push to eradicate energy poverty and enable their citizens to utilize electricity, this is obvious by the fact that 25 countries in the region joined the United Nations Development Program and UN Capital Development Fund Global Clean Start program [20]. More countries are going to collaborate to have regional pools that will solve the problem of isolation which makes it more difficult and complex to generate and transmit electricity across the regions of the continent. This will help countries support each other by sharing infrastructure but will require the transmission lines across regions [33]. This energy collaboration will reduce environmental impacts, ensure energy security, and make energy more affordable [34]. Ground-breaking technologies that maximize the efficiency of energy-consuming devices such as cooking stoves and processing systems will be employed more and deployed to rural areas across the continent to minimize waste and salvage energy. The funding of innovative technologies and research will enjoy the support of the governments of the region [10]. New models for urban development will be designed and implemented and increase access to electricity to help alleviate poverty and provide opportunities and employment as nearly all businesses such barbershops and saloons, poultry, carpentry, welding, internet café, and many more rely on electricity [27].

Researchers have shown that not only can RE be integrated into the power sector in SSA to solve the energy challenge, but that it can account for 100% of the energy supply of the region by 2030. This integration will be done through Integrated Green Energy Resource Planning (IGERP), with emphasis on the impacts on energy delivery and consumption systems and also the decentralization of the grid system [5]. Also, at least 1000TWh will be saved through the high energy standards and efficient technology mostly in heating for industrial and commercial processes and in cooking and air conditioning systems [22]. It is possible to have 100% renewable energy sources in SA, but challenges remain especially the lack of proper regulatory frameworks and inconsistent regulations. The temptation of fossil-based energy systems is one that is still too strong to be resisted by most of the governments of SSA, and therefore the unwillingness and sheer lack of commitments in energy transition on their part [7]. The private sector and all other well-meaning stakeholders obviously must play a role in achieving its seamless energy transition for sub-Saharan Africa in the future. Governments will also need to collaborate within the region to maximize the potential of RE and reduce the costs of implementation and transition.

Renewable Energy will become the main sector for energy generation and will account for several mini-grids and contribute majorly to the existing grid and not just a small part of the grid. Governments in sub-Saharan Africa will begin to invest more [22] and carry out more feasibility studies on the impact of RE in their localities with country-specific assessments which are detailed and systematic with rules of the game to protect rural dwellers from losing land to those seeking to grow energy crops and establish RE schemes. They must however ensure the right policy and framework and support for such schemes and this could guarantee up to 100% dependence on renewable energy. The benefits of energy schemes, whether they are renewable or hybrid systems, must impact the general populace and the rights of citizens and communities must be protected [16]. Governments will also take the lead in promoting biofuels and RE and support private sector [16] through interventions in governance, taxation, regulation, and technology.

Transparent policies to woo investors are slowly being implanted by the governments of SSA and sustained in the region with very attractive incentives for investors and collaborators in energy schemes. On the flip side, carbon taxes must be implemented to discourage further reliance on fossil fuels and as well encourage the use of renewable and clean energy to reduce carbon footprints. These taxes may lead to an initial hike in tariffs, but will slowly reduce with sustained RE development. Every area of the economy and all stakeholders including the rural dwellers must be part of the transition and this will require relentless efforts from governments of the countries. Dilemmas for policymakers will remain as they may struggle to choose between using resources such as land or finance for food or fuel, and speedy wealth creation, or the negative effects on the environment [16].

7 Conclusions

An increase in small scale off-grid energy plants will create positive impacts by improving the efficiency of the power sector and reaching the rural areas [35], this can be achieved through the integration of several or large RE systems and the implementation of smart grids which is critical for a sustainable energy transition [9]. Most RE schemes need to be implemented or supported by IPPs and managed by companies that have sufficient skilled and experienced project developers with the required technical and financial capabilities. The success of the IPPs will depend on the level of implementation of set regulations, and governments must strive to reduce risks that could affect IPP and seek solutions to already existing problems. A level playing field must be provided for all IPPs to boost their confidence and make them more willing to invest. The future of energy is already shaping up and renewable energy can compete with and substantially replace fossils if the right things are put in place. This is a necessary requirement for a sustainable and successful energy transition [27], Biomass remains a dominant renewable energy source as it is the cheapest and most reliable energy source currently on the continent despite the fact that PV dominates the scene currently in electric energy generation. Geothermal energy can go a long way in supporting the energy transition plans of SSA even though it is not currently as popular as the other RE methods of energy generation and it remains confined to specific regions. Climate change remains a matter of concern as it affects the nature of RE sources especially hydro renewable energy sources which are already presently lacking or slightly diminished in some locations across SSA. Tackling the effects of climate change must be met with a determination to sustain and preserve the sources of renewable resources and all stakeholders must be involved in this.

References

1. IEA (2019) Africa energy outlook 2019. World Energy Outlook Spec Rep 288
2. Kebede E, Kagochi J, Jolly CM (2010) Energy consumption and economic development in Sub-Sahara Africa. Energy Econ 32(3):532–537
3. Avila N, Carvallo J, Shaw B, Kammen DM (2017) The energy challenge in sub-Saharan Africa: generating energy for sustainable and equitable development. Oxfam Res Backgr Ser 100

4. Vale Media Group (2018) Sub-Saharan Africa Power 2018. Africa energy portal. https://africa-energy-portal.org/events/sub-saharan-africa-power-2018#:~:text=Per capita consumption of electricity, that in high-income countries
5. Suberu MY, Mustafa MW, Bashir N, Muhamad NA, Mokhtar AS (2013) Power sector renewable energy integration for expanding access to electricity in sub-Saharan Africa. Renew Sustain Energy Rev 25:630–642
6. Koçak E, Ulucak R, Dedeoğlu M, Ulucak ZŞ (2019) Is there a trade-off between sustainable society targets in Sub-Saharan Africa? Sustain Cities Soc 51
7. Barasa M, Bogdanov D, Oyewo AS, Breyer C (2018) A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030. Renew Sustain Energy Rev 92:440–457
8. Vanadzina E, Pinomaa A, Honkapuro S, Mendes G (2019) An innovative business model for rural sub-Saharan Africa electrification. Energy Proced 159:364–369
9. Bazilian M et al (2012) Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. Util Policy 20(1):1–16
10. Owen M, van der Plas R, Sepp S (2013) Can there be energy policy in Sub-Saharan Africa without biomass? Energy Sustain Dev 17(2):146–152
11. The World Bank (2020) Africa development indicators. Data Cat
12. Navarro ADLV (2012) Energy economics: concepts, issues, markets and governance. Int J Energy Sect Manag 6:145–149, Bhattacharyya SC (2011) Energy economics: concepts, issues, markets and governance, p Springer, p. 538. ISBN: 0857292676
13. Karekezi S, Kithyoma W, Initiative E (2003) Renewable energy development. In: workshop on African energy experts on operationalizing the NEPAD energy initiativepp, pp 2–4, June 2003
14. Dioha MO, Kumar A (2020) Exploring sustainable energy transitions in sub-Saharan Africa residential sector: the case of Nigeria. Renew Sustain Energy Rev 117:109510
15. Tiyou T (2016) The five biggest wind energy markets in Africa. Renew Energy Focus. http://www.renewableenergyfocus.com/view/44926/the-five-biggest-wind-energy-markets-in-africa/
16. Jumbe CBL, Mkondiwa M (2013) Comparative analysis of biofuels policy development in Sub-Saharan Africa: the place of private and public sectors. Renew Energy 50:614–620
17. Krausmann F, Erb KH, Gingrich S, Lauk C, Haberl H (2008) Global patterns of socioeconomic biomass flows in the year 2000: a comprehensive assessment of supply, consumption and constraints. Ecol Econ 65(3):471–487
18. Kruger W, Stritzke S, Trotter PA (2019) De-risking solar auctions in sub-Saharan Africa—A comparison of site selection strategies in South Africa and Zambia. Renew Sustain Energy Rev 104:429–438
19. Iwayemi A (1998) Energy sector development in Africa. African Dev Bank 1–23
20. United Nations (2012) the secretary-general's high-level group on sustainable energy for all: report of the co-chairsm p 32
21. Moner-Girona M, Solano-Peralta M, Lazopoulou M, Ackom EK, Vallve X, Szabó S (2018) Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: reducing the gap between current business models and on-site experience. Renew Sustain Energy Rev 91(March):1148–1161
22. Greenpeace International (2015) Energy [R]evolution—a sustainable world energy outlook 2015. Energy Revolut
23. IEA (2016) IEA renewable energy 2016 mid-term market report
24. The Forum of Energy Ministers (2006) Energy and the millennium development goals in Africa the forum of energy ministers of Africa
25. Bosshard P (2012) How renewable energy solutions reduce poverty around the world. Huffpost
26. Joint UNDP and World Bank (2005) Power sector reform in Africa: assessing impact on poor people repossessing impact on poor people
27. Eberhard A, Gratwick K, Morella E, Antmann P (2017) Independent power projects in Sub-Saharan Africa: investment trends and policy lessons. Energy Policy 108:390–424
28. IEA (2017) Energy access outlook 2017; from poverty to property

29. Davidson O, Mwakasonda S (2004) Electricity access for the poor: a study of South Africa and Zimbabwe. Energy Sustain Dev 8:26–40
30. The African Societiy of the National summit on Africa (2008) Addressing environmental problems in Africa, Africa Soc.
31. Visagie E, Prasad G (2006) Renewable energy technologies for poverty alleviation South Africa: bio diesel and solar water heaters. Univ. Cape Town, South Africa
32. Acemoglu D, Robinson J (2014) Why nations fail. Rev Za Soc Polit 21(3):381–383
33. Rosnes O, Vennemo H (2012) The cost of providing electricity to Africa. Energy Econ 34(5):1318–1328
34. Nyabadza MC (2012) Overcoming energy constraints on future development in Stellenbosch through energy efficiency : retrofitting of solar water heaters and gas stoves in middle and high income households in the residential sector
35. Chakamera C, Alagidede P (2018) Electricity crisis and the effect of CO_2 emissions on infrastructure-growth nexus in Sub Saharan Africa. Renew Sustain Energy Rev 94(June):945–958
36. IEA (2019) Global energy and CO_2 status report. https://www.iea.org/world
37. SOLARGIS (2019) Global solar irradiation (GHI) for Sub-Sahara Africa. https://solargis.info/
38. Department of Wind Energy (2019) Onshore wind speed for Sub-Sahara Africa. https://www.energy.gov/eere/wind/wind-energy-technologies-office