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A review on the recent progress made on solar photovoltaic in selected countries of sub-Saharan Africa

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Abstract:

The harmful effects of carbon emissions and carbon dioxide caused by overdependence on oil is a global issue, which is currently being addressed by encouraging renewable energy (RE) resources contribution to the energy mix. Encouraging RE is important in order to solve the unsustainable nature of electricity generation especially in the sub-Saharan African countries. One of the REs that have vast potential especially in sub-Saharan Africa is the solar energy. This paper provides an overview of the solar photovoltaic (PV) developments in selected countries of sub-Saharan Africa - in terms of research, installed capacity, solar radiation level, RE policies and the percentage of solar PV in the future energy mix of these countries. Finally, this paper identified the barriers to RE deployment and proposed scaling-up solar PV as one of the solution in the development of energy mix in these countries.

Keywords: solar energy; solar photovoltaic; sub-Saharan Africa; renewable energy.

1. Introduction:

Carbon dioxide (CO_2) and other global warming emissions are the current challenges facing the humanity across the globe. These emissions can have serious harmful impacts on the environment, climate and health. One of the major causes of this emission is over dependence on fossil fuel as a primary source of energy, such as natural gas, coal and oil. These fossil fuels are non-renewable and can diminish with time. The usage of fossil fuel often associated with negative impacts. One of the biggest environmental disasters of fossil fuel is the Gulf war oil spill during the Iraqi evasion of Kuwait in 1990. The Iraqi Army opened valves of some oil terminal into the Gulf as a preventive measures to prevent American Air Force from landing and it resulted in slick of 11,000 km^2 and 12.7 cm thick [1]. Another example is the British Petroleum (BP) oil ring explosion in America in 2010 which had a serious effect on wildlife and threatens fishing industry and the deep waters in that area [2]. This occurred after an oil/gas mixture escaped from the leakage of the borehole and subsequently ignited into a fireball when it reached the surface ring [2]. As a result, 11 people were killed and the wildlife and the environment experienced extensive damage [2]. Besides that, another catastrophic event is the West Virginia Massey Energy Coal mine explosion that killed 29 people in the USA is another quick reminder of how coal mines are dangerous [3]. The respiratory problem from the coal does not only affect miners only, but also the particles that are released to the atmosphere when coal is burned to generate electricity increases the risk of asthma attacks for those living in the area and are estimated to kill up to 30,000 lives in the USA yearly [4].

Since it is now evident that it is better for the world not to rely on conventional energy sources in the long run, research on several options are currently ongoing. One solution is opting for renewable energy (RE) sources which offers considerable environmental and public health benefits. Substituting fossil fuels with RE reduces early mortality and general health care expense [5]. RE has many advantages which include [6] (i) sustainability and barely impossible to run out; (ii) RE equipment is easy to maintain and has low operational cost; (iii) RE produces basically little or no waste products or chemical pollutants that are harmful to mankind; (iv) also RE projects could provide economic benefits and opportunities for the locals in rural areas as most RE projects are located away from densely populated urban centers.

Currently, global attention has been drawn to the fact that RE is vital not only in addressing climate behavior, but also in creating new opportunities for better livelihood of billions of people around the globe. Therefore many countries are now shifting towards RE as the major energy source and as an alternative to electricity power generation [7]. Recent global RE annual status report [8] shows that RE provided 19.1% of the world final energy utilization in 2013 (see Figure 1), and the capacity is expected to grow further. The most rapid increase in capacity occurred in the power generation sector mostly made up of the solar PV, hydropower and wind.

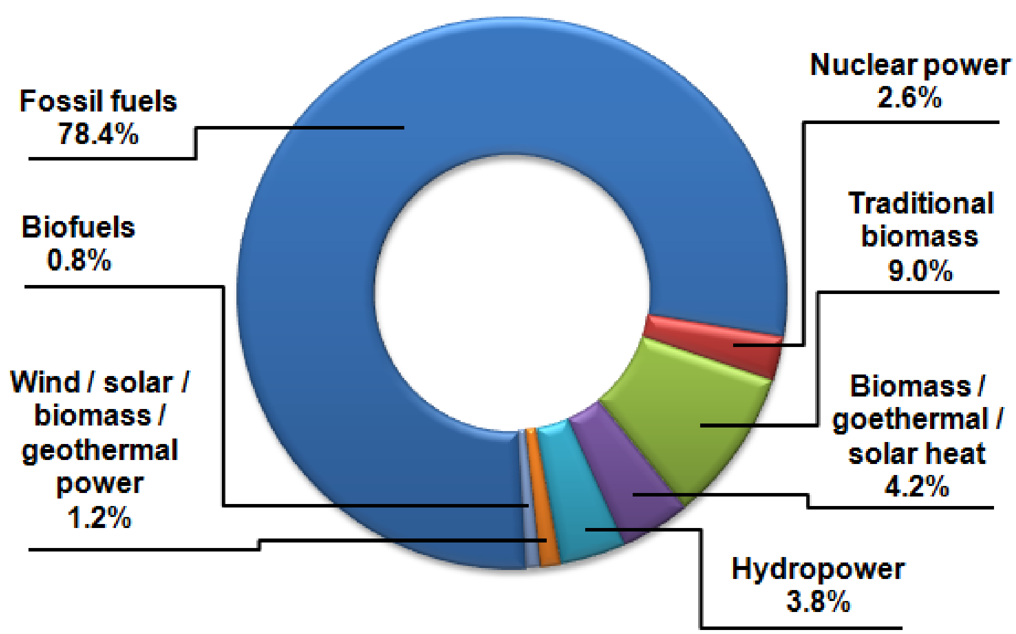

Figure 1: Estimated RE share of the world's final energy consumption in 2013. Adapted from [8].

Figure 2 shows the average annual growth rate expansion by 2014 in terms of capacity installation and production for all RE technologies in the world. It is evidence that solar technologies (solar PV and concentrating solar power (CSP) systems) growth rates are higher than other RE technologies [8,9]. From Figure 2, it is also evident that all RE technologies have higher deployment rate in 2014 than the preceding years [8]. There is increased capacity installation in the heating sector at a steady pace (by 9% when compared with the previous year) while biodiesel and ethanol production for transportation sector also experience some increment at production level (by 7.1% and by 13% respectively when compared to the previous year).

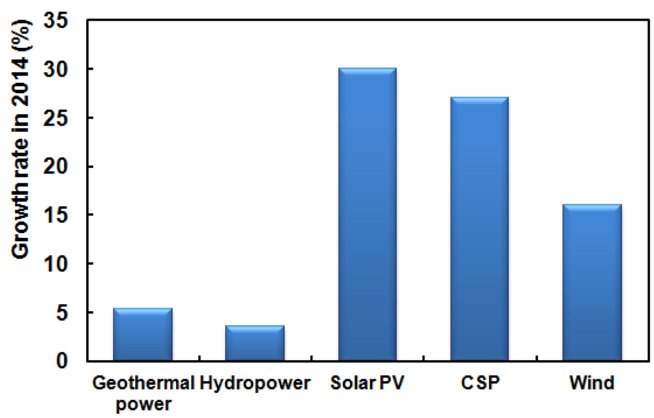

Figure 2: Average annual growth rate of RE capacity in power generation in 2014. Adapted from [8].

Despite several benefits of RE, it has some drawbacks and disadvantages. The spatial energy density of RE is low compared to most fossil fuels [10]. In some cases, space is needed to convert these renewables and deliver them to the end users. To obtain the best results from RE implementation, it is vital to recognize the correct type of technology for a particular country [11]. A number of factors such as efficiency of the RE, water or land requirements and the socio-economic impacts of the RE technology, are necessary for optimum RE output [12,13].

Solar energy has been recognized as one of the promising energy sources that can aid the future security of energy supply [14,15]. Solar energy does not deplete and do not produce waste products or carbon emissions [16]. Several applications of the solar energy exist, for example: electricity power generation, solar desalination, room temperature control and solar propulsion [17]. Solar technologies are basically divided into two categories, i.e. the solar thermal system and solar PV system. Each of these technologies can be either standalone or grid connected. The solar PV can be used for many applications such as small home system for lighting, telecommunications, and mini-grid system, water pumping and commercial systems [18,19]. Solar PV converts sun light intensity directly to usable electrical energy. One merit of PV modules is their ability to produce electricity even during winter and cloudy weather at a reduced rate [18]. PV can operate automatically and possess minimal maintenance requirements and currently the lifetime of many PV panels is approximately 25 years [17,18]. On the other hand, solar thermal systems apply sun's energy for heating, evaporation and drying system. Already solar grain dryers and water heaters are applied in many developing countries [20,21].

However, there are negative effects caused by these solar technologies. The panels perform at lower power quality depending on climate conditions (e.g. cloud drift [22,23], wind speed [24] etc.). It is also necessary to clean the panel from dust and dirt to ensure that the maximum power could be generated from the panels [25,26]. There are also issues related to building aesthetics and probably accidental release of chemicals, such as cadmium and sulfur hexafluoride [27]. To address these problems, several governments have made policies that can go a long way to prevent social and environmental effects. These include recycling of PV panels at the end of its lifetime and making the producers responsible for final disposal of these apparatus [28]. The solar PV market has witnessed tremendous growth over the last few years. The cumulative global solar PV installation rose up to 177 GW in 2014 with 49% of them were installed in Europe [8]. Figure 3 shows the trend of solar PV market from 2004 to 2014.

This paper aims to provide a broad review on solar PV progress made in selected countries of sub-Saharan Africa. These include Nigeria, Cameroon, Angola, Ethiopia, Ghana, Kenya, Rwanda, Senegal, South Africa and Tanzania. Based on literature surveys, these countries are chosen since they showed the most development as compared to rest, in terms of total power capacity installed, RE policies in place, attracting investment etc. [8,29].

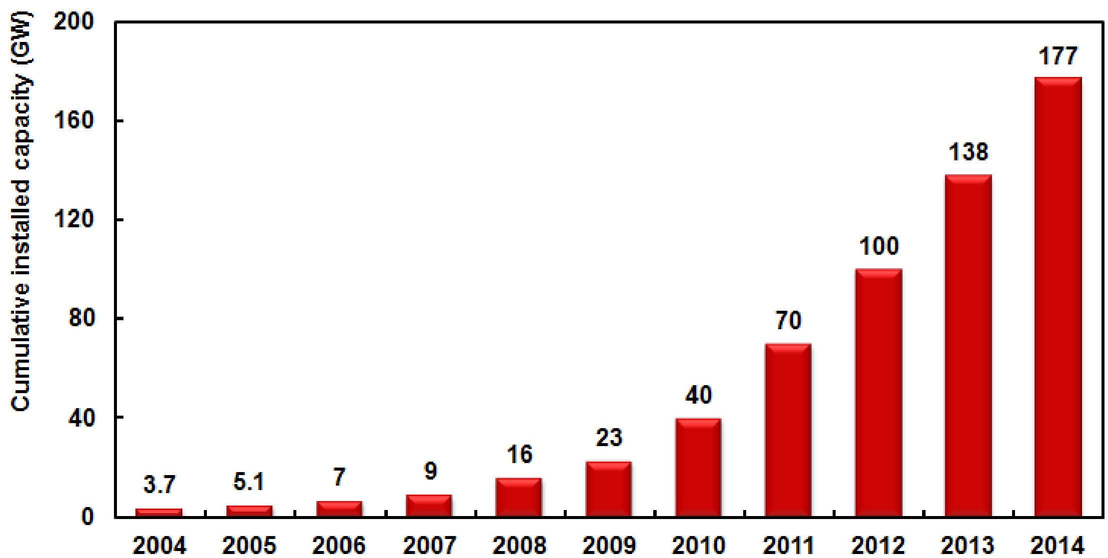

Figure 3: Cumulative solar PV installation in the world. Adapted from [8].

2. Sub-Saharan African Countries Background

Sub-Saharan Africa refers to all Africa except the five mainly Arab states of North Africa (i.e. Algeria, Morocco, Egypt, Tunisia and Libya) and Sudan which is regarded as a north-central African state [30]. Sub-Saharan Africa is made up of 49 of African countries out of the 54, as illustrated in Figure 4.

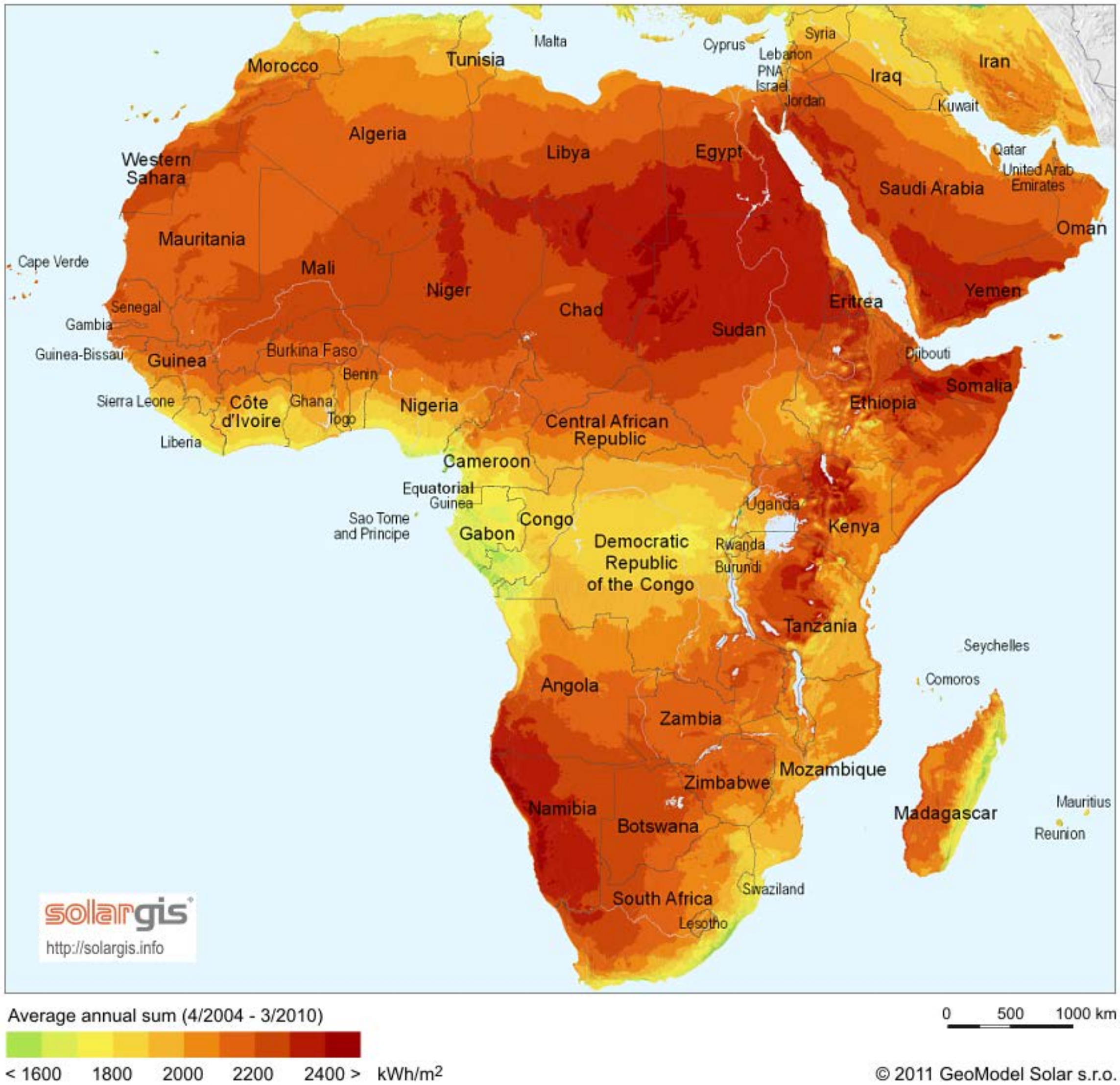

Figure 4: Map of Africa showing countries within the sub-Saharan Africa and their average annual solar radiations [31].

As at 2010, the sub-Saharan African population is about 853 million people, making it the highest population growth rate in the world [32]. Currently, the sub-Saharan Africa has experienced high-economic growth, but the rapid growth in population has made the gross domestic product (GDP) per capita increasing slowly [32]. Though policies are created in most of these countries to increase the local energy provision but the current situation of the sub-Saharan energy system is seriously hampering the region's economic anticipation. The largest energy demand countries in Sub-Sahara Africa are Nigeria and South Africa, which account for 40% energy demand in the region. Most of the energy uses are in residential sector, mostly biomass for cooking [33]. Currently there is an increase in energy access across the sub-Saharan African countries but energy services are inadequate. More than half of the population in the sub-Sahara Africa does not have access to electricity [34]. The on-grid power generation capacity in Sub-Sahara African countries in 2012 was 90 GW with South Africa producing half of it [35]. The power was supplied from coal (45%), hydro (25%), 17% oil while for the balance is supplied from gas [35]. Over the last 5 years, one-third of the world's oil and gas findings were in sub-Saharan Africa but they now faced the biggest challenge to convert these resources into revenue for the benefit of their citizens [35]. In sub-Saharan Africa, RE market has developed tremendously in private sector. Unfortunately, no reliable data on investments is available in the literature [8]. However recent survey carried out in *Climatescope 2015* report on sub-Saharan Africa [36] shows that South Africa has the highest investment in RE of about USD$16bn, followed by Kenya and Ethiopia (see Figure 5). Interestingly, solar energy appears to be the sector receiving more funding up to 2015. The highest funding was in 2012 and thereafter started declining due to delays in financing projects.

Sub-Saharan Africa has abundant renewable energy sources which have remained unexploited. There is excellent solar energy potential across all the Sub-Saharan countries, wind mostly within the coastal areas, hydro and geothermal mostly concentrated in the East African valley [37]. Since this paper is focused on solar energy, other types of RE sources are not discussed here. Figure 4 shows the average annual solar radiation in sub-Saharan African countries.

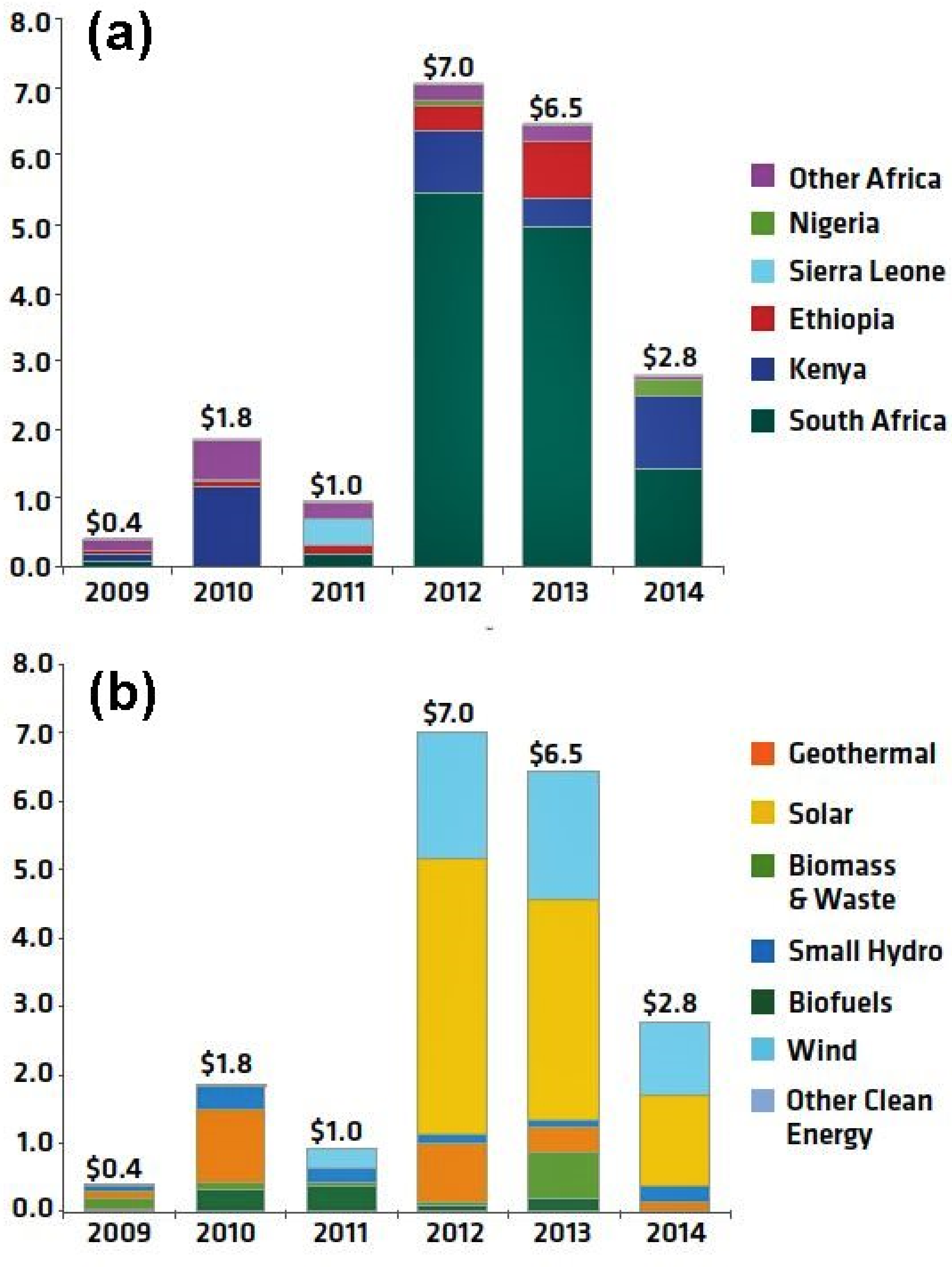

Figure 5: Total investment in RE in sub-Saharan Africa (2009-2014): (a) by country, and (b) by the type of technology [36].

3. Solar PV in sub-Saharan African countries

3.1 Nigeria

Nigeria has adequate solar radiation that can be utilized for power generation. The highest daily solar radiation is about 7 kWh/m^2 in the northern part of the country and approximately 4 kWh/m^2 in the southern region [20,38]. Most part of Nigeria receives an average of 6.5 sunshine hours per day [39]. As a result of power shortage in most part of the country, solar energy is currently utilized for home power supply and street lightning. There is also solar PV-lighting in public places and hospitals. The current installed capacity of solar PV in Nigeria is 15 MW, mainly for standalone power supply with no solar power plant connected to the grid system [40].

Apart from the solar potentials, Nigeria has other energy sources such as oil, hydro, biomass and gas, [20,41] as illustrated in Figure 6. The Nigeria's National Energy Policy has been approved by the senate since 2003 [42]. This policy addresses issues and challenges currently encountered in the energy sector. In this policy, RE has been mentioned as one of the priorities for future power generation. The government of Nigeria has already included solar energy targets on a short, medium and long terms as shown in Table 1. Nigeria targets 5% of generation energy mix for RE by 2020 [43] according to the recent Electric Power Sector Reform Act 2005. The Nigeria's power minister mentioned a boost to the energy needs with 1GW of solar power over the next 10 years. Germany has already committed to invest up to €20million to boost the Nigeria's energy by 6500MW, of which 500 MW will be from solar energy [43]. Moreover, the government of Nigeria signed a memorandum of understanding with a USA firm (New Technology Industry) to supply up to 1200 MW of solar PV projects worth USD2 billion which are expected to be completed within the next 2 years [25].

Nigeria is regarded as one of the countries in sub-Saharan Africa to have utilized the state capital to support local solar companies for local manufacturing [29]. Table 2 shows some sub-Saharan African solar projects and the panel manufacturers. Recently, Ike [44] investigated the effect of the ambient temperature on the performance of a stand-alone solar panel at a university in the Eastern part of Nigeria during rainy and dry seasons. The system comprises of a PV generator, Deep Cycle Trojan batteries, LED lamp heads, circuit breakers and maximum power point tracking (MPPT) charge control. From this study, it was confirmed as it is known that there is indirect proportionality between ambient temperature and the output power. This clearly implies that solar panels in Nigeria needs to be installed at areas with more air currents to keep the temperature low while maintaining maximum output efficiency.

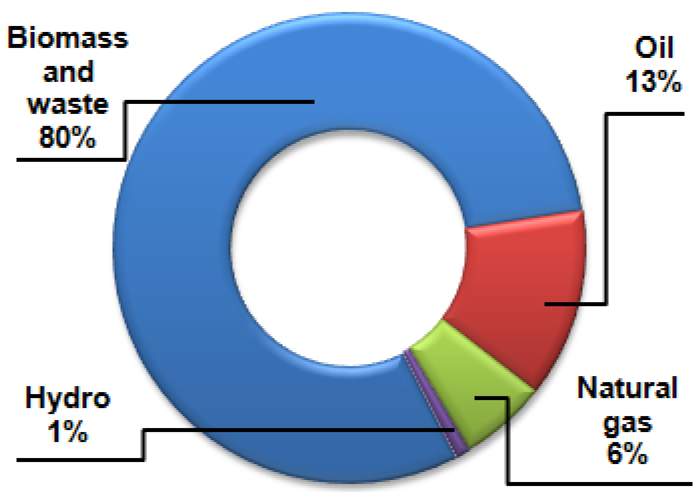

Figure 6: Total primary energy consumption in Nigeria in 2012. Adapted from [45].

Table 1: Solar progress targets in Nigeria [40].

No	Activity/Item	Timeline/Quantity		
		Short (2006-2009)	**Medium (2010-2015)**	**Long (2016-2030)**
1	Solar PV Home Systems (SHS) (MW)	5	10	15
2	Solar PV Water Pumping (MW)	50	1,000	5,000
3	Solar PV Community Services (MW)	45	500	3,000
4	Solar PV Refrigerators (MW)	20	500	2,000
5	Solar PV Street and Traffic Lighting (MW)	100	1,000	10,000
6	Solar PV Large Scale PV plants (1MW)	80	990	9,990
7	Solar Thermal Electricity (1MW)	300	2,136	18,127
	Total (MW)	**600**	**6,136**	**48,132**

Table 2: Solar projects and panel manufacturers in Africa [29].

Name	Country	Panel technology	Power range (Wp)
Micro Care	South Africa	Polycrystalline	75–280
MLT Drives	South Africa	Monocrystalline, polycrystalline	
Rentech	South Africa	Polycrystalline	10–30
Karshi Solar Panel Plant NASENI	Nigeria	Production of solar cells and panels from imported silicon wafers and solar cells	7.5-MW panel
The Nzema project	Ghana	Concentrated solar power	155 MW plant
Ubbink East Africa—a joint venture between the Dutch Ubbink and Kenya's Chloride Exide	Kenya	Production of solar cells and panels import broken solar cells mainly from the Netherlands and then reworked into smaller units	
Setsolar	South Africa	Polycrystalline	25–280
Solaire direct Technologies	South Africa	Polycrystalline	70–250
Standby Power Technologies	Kenya	Monocrystalline, polycrystalline	12–160

3.2 Cameroon

Cameroon has also huge solar potential which is yet to be tapped. Most part of Cameroon receives an average of 8.2 hours sunshine hours per day [46]. In most part of the country, the mean solar radiation is approximately 5.8 kWh/m^2/day [47]. The electricity generation capacity of Cameroon is at 817 MW of which hydroelectricity accounted for 80% of this energy while thermal energy supplies the remaining 20% [20]. The electricity demand for Cameroon is forecasted to reach 5000 MW by the year 2020 [20]. The available energy sources in Cameroon are hydro, solar, wind, geothermal and biomass [48]. Figure 7 shows the primary energy demand in Cameroon.

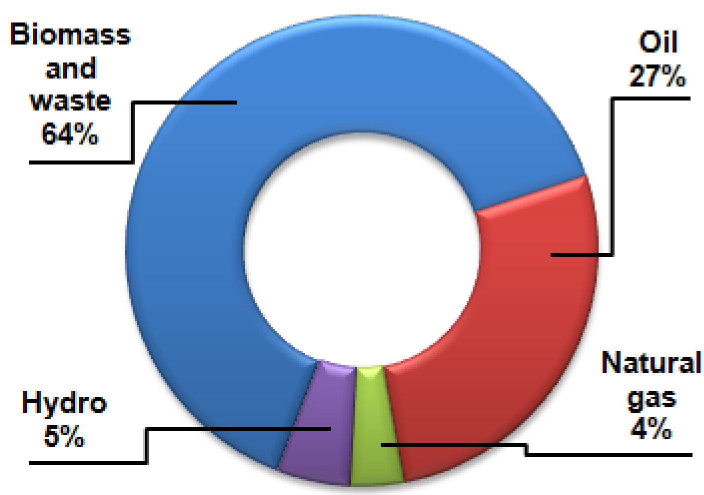

Figure 7: Total primary energy consumption in Cameroon in 2011. Adapted from [41].

The government of Cameroon is yet to made adequate development in the RE sector. There is also lack of policy development in the sector that is hindering local as well as international investors to invest in the RE sector. However, there are some recent development in solar powering of street light in big cities such as Douala and Yaounde [38,48]. Cameroon has already installed “e-kiss” (energy-keep it simple and safe) mobile off-grid PV systems from Antaris solar ESI-Africa [49]. In spite of this small development, there are many factors which hinders its prospect including poor maintenance and dust covering solar cells in those streets.

3.3 Ghana

Ghana is endowed with abundant solar radiation that can be utilized for power generation. In Ghana, the average solar radiation was found to be 5 kWh/m^2 per day and the duration of sunshine per day is between 5 and 8 hours [50]. There is higher solar radiation in the northern part of the country as compared to the southern part. It was estimated that 4000 off-grid photovoltaic systems have been installed all over the country [51]. Currently, Ghana has 20 grid-connected solar power stations with a total capacity of 3 MW and has 41,820 off-grid solar plants which has a total capacity of 0.8 MW [52].

Figure 8 shows the total primary energy consumption in Ghana in 2013. The fossil fuels constituted 47% of the total energy demand followed by wood at 42% and hydro at 8% [53]. As at 2013, the yearly peak demand of electricity in Ghana was 1943 MW and supply was inadequate to meet up with the growing electricity need of the country [54]. This was caused by the inconsistent supply of natural gas from neighbouring country and insufficient water level to run hydro dams to their full capacities.

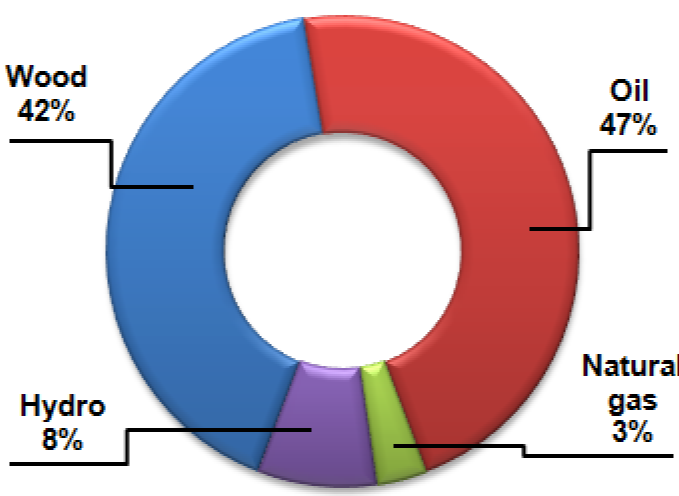

Figure 8: Total primary energy consumption in Ghana in 2013. Adapted from [53].

Ghana has already developed a RE policy [52]. This policy highlighted the need for the contribution of RE sources (including wind, hydro, biomass and solar) by 10% for off-grid, mini grid and grid-connected by the year 2020. One of the key provisions provided in the RE Act of 2011 [55] is that a RE fund is introduced as an incentive for the development and promotion of RE sources. Specifically, there is need for the establishment of RE authority saddled with the responsibility of managing and implementing RE assets mainly off-grid electrification. Since the passage of the country's RE Act 2011, progress has been made in RE sector, especially the solar energy. Last year, the feed-in tariff has been made for utility scale grid energy interconnection. The feed-in tariff for solar without grid is GHS0.5836/kWh (USD0.153/kWh) while that with grid is GHS0.64/kWh (USD0.168/kWh) [52]. A 115 MW solar plant is scheduled to be completed by 2015 [43]. Presently, Ghana is in the process of building the largest solar PV plant in the world [56,57]. The facility is estimated to cost about USD400 million and will include 630,000 solar PV modules to generate up to 155 MW.

3.4 South Africa

The large proportion of South Africa's primary energy consumption comprised of fossil fuels (97%), and the rest was from nuclear and renewables, as presented in Figure 9 [58] . The country is endowed with abundance solar radiation as most African countries in the Sub-Sahara. The average sunshine hours in South Africa is 8.5 hours per day [59]. The mean solar radiation is between 4.5 and 6.5 kWh/m^2 per day [60]. South Africa has one of the highest solar radiation especially in the Northern Cape Province with an average of more than 6.5 kW/m^2/day [61]. The other areas of high radiation includes the Free States, Limpopo, North West, Eastern Cape and Interior Pars of Western Cape [61]. Recent studies shows that Upington in the Northern Cape of South Africa has solar potential of producing about 5000 MW of electricity [61]. As of April 2015, there are 415 solar PV installations in South Africa, with installed capacity of 36.5 MW [62].

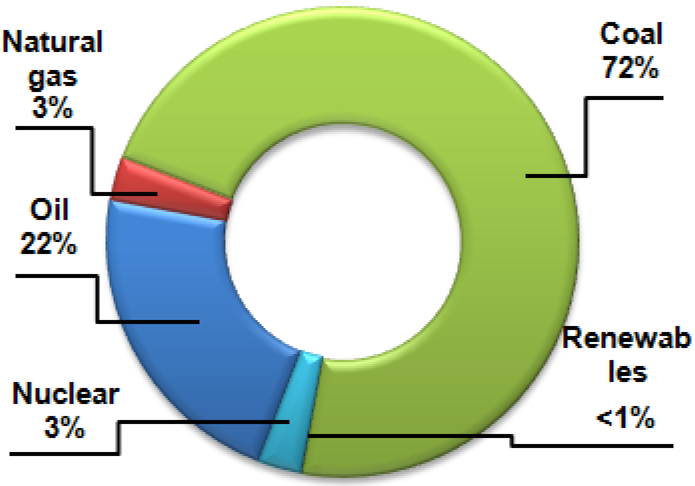

Figure 9: Total primary energy consumption in South Africa in 2013. Adapted from [58].

The South African government has already developed RE policy which led to the White Paper on Energy Policy of 1998 [63]. It was highlighted that the government will pay immediate attention to RE technologies such as solar PV, hydro and wind. Some of the objectives of this 1998 white paper include improving energy services and encourgaing economic development [40]. Afterwards, the 2003 White Paper on Renewable Energy [64] was made public, where it was clearly stated the 10-year target plan for sustainable energy industry of the country. It was proposed that 10000 GWh being added to the final energy consumption by 2021 will be from RE sources such as wind, solar, biomass and small scale hydro. In 2009, South Africa introduced a feed-in tariff scheme but it was abandoned in 2011 to allow a more viable bidding process [65].

The solar PV market in South Africa enjoys a prosperous year in 2014, and it was ranked 9th in the world with an installation of 0.8 GW [8]. South Africa proposed a solar park in Northern Cape Province [29,66]. This park is expected to create up to 12,300 jobs [29,66]. In the long run, South Africa targets to raise RE supply from 1% to 12% by 2020 [43]. Plans are been considered to raise the generating capacity from 42 GW to 59GW by 2018 [43]. In this plan, RE will account for 21% including 1.5 GW of solar capacity [43]. The Jasper solar PV power plant recently completed in South Africa is one of the largest in Africa [67]. It is located in the northern cape province of South Africa. The plant is capable of generating 180 GWh of RE that can supply power to 80,000 homes. It covers up to 180 hectares of land and has more than 325,000 multi-crystalline modules with each one has a power rating of 295 W.

Recently, Eskom has compared the performance of crystalline silicon and thin-film copper indium gallium selenide (CIGS) technologies for a 400kWp solar PV plant in order to understand their behavior in winter and autumn seasons in South Africa [68]. Eskom shows that poly-crystalline solar panels have comparatively higher module efficiency when compared to thin-film. In contrast, thin-film CIGS technology has higher performance ratio (or system efficiency) of 88% as compared to 78% for the poly-crystalline solar panels.

3.5 Kenya

Kenya is located within the equator region and this gives the country the prospect for a flattering solar promotion. The country has an average of 5 peak sunshine hours per day [69]. The mean solar radiation level per day is between 4 and 6 kWh/m^2 [69]. There is high solar potentials in the northeastern and the eastern part of the country, more specifically in coastal areas [70]. The number of household ownership of solar PV in Kenya is very high and it is estimated that about 30,000 smallsystems (i.e. 20-100 W perhousehold) sold per year [71,72]. The current on-grid solar PV installation is 1.3 MW [73]. Besides that, solar energy is also used for water heating, crop and fish drying and small PV stations for electricity generation [69].

The primary energy sources in Kenya are biomass, oil, hydro and coal, as indicated in Figure 10 [69,74]. The Kenyan government has already developed a policy on RE [74], in which solar energy is taken into account. The Kenya's Ministry of Energy and Petroleum is in charge of developing and implementing this policy. The first national policy was introduced in 2004, contains procedures to be taken by the government in order to promote the use of RE. The RE policy and strategies for Kenya have been categorized into short-term, medium-term and long-term [74]. Some of the key points related to solar energy in the RE policy include awareness activities to encourage solar energy development, enforce policy on standards, provision of incentives for local entrepreneurs, enforce penalty for vandalisation of solar energy infrastructure and supporting research and developmnet on solar technology.

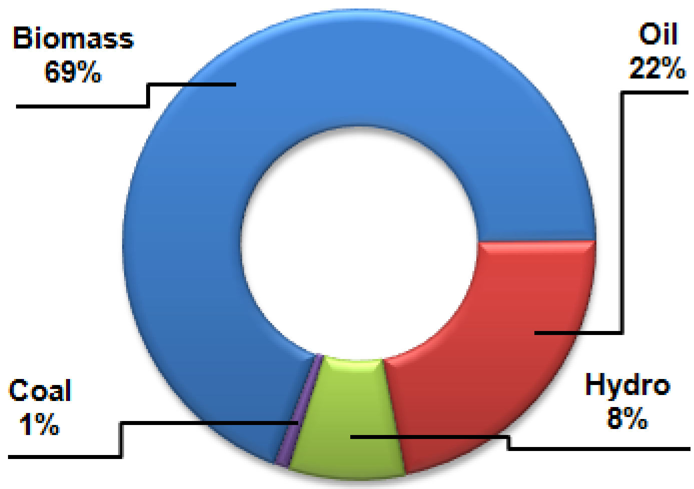

Figure 10: Total primary energy consumption in Kenya in 2014. Adapted from [69,74].

Currently, the Kenya's government has set up a solar institution to train locals [43]. The government of Kenya has put in place bank loan facilities to purchase solar PV panels from Kenya-based model manufacturers. There is also a feed-in tariff scheme for on-grid electricity which has a tariff rate of USD 0.12/kWh for installed capacity of 0.5 MW up to 40 MW projects [75]. In Kenya, a small scale PV module firm i.e. Ubbink East Africa has established mutual collaboration between local and international companies for local manufacturing of solar panels (see Table 2).

3.6 Senegal

Senegal has an average of between 9 and 10 hours per day [76], and the solar radiation level is up to 2000 kWh/m^2/year, approximately 5.5 kWh/m^2/day [77]. This indicates that Senegal has the potential for good solar energy development projects. Biomass is the primary energy supply in this country, accounting for 54%,oil for 40% and others including hydro and coal making up the remaining 6% (see Figure 11) [77].

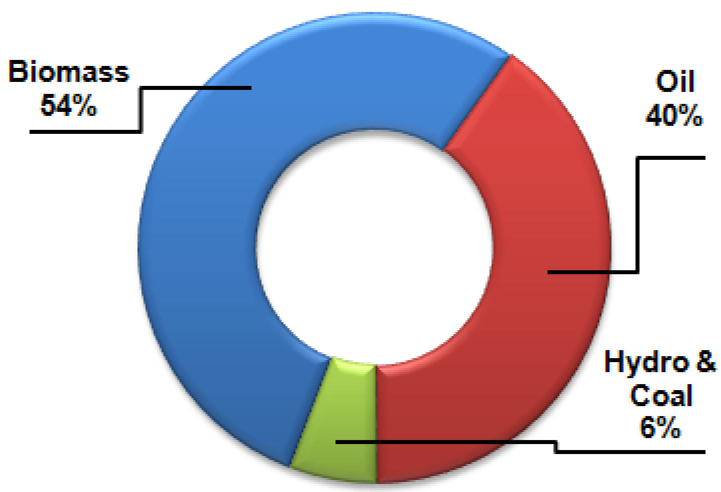

Figure 11: Total primary energy supply in Senegal in 2012. Adapted from [77].

Senegal is the first West African country to have passed a RE Law, where solar is the main source of energy [43]. The country has the first solar PV manufacturing plant in the entire West Africa with an output of 25 MW annually [43]. The country started developing RE since 1962 but at that time, it was only at the pilot stage. Several measures taken back then were not enough to fully exploit the RE resources. In the 1970s and 1980s, there were legal provisions that provides incentives for RE technogies [78]. The Electricity Reform Law of 1998, introduces vital reforms aimed at promoting the access of electricity by independent operators [78]. Since 2010, progress have been made in RE development which include promulgation of two laws on the promotion of biofuels and

RE (Law No. 2010-21 and Law No. 2010-22). This is followed by the implementation of Decree No. 2011-13, relating to the procurement and benefit of electricity from renewables and their interconnections to the grid. Thereafter, many decrees were adopted.

3.7 Tanzania

Similar to other sub-Saharan African countries, Tanzania has high solar radiation of about 4-7 kWh/m^2 per day [79]. The average sunshine hours per day are between 8 and 10 hours [80]. Solar resources are being developed for both off and on grids at the central region of the country. In Tanzania, 6 MW of solar PV electricity is installed all over the country for various applications such as health centres, schools, hospitals, telecommunication enterprices, street light and also police post [79].

Apart from solar energy, Tanzania is endowed with other energy resources which are unexploited. These comprises of hydro, biomass, uranium, natural gas, coal, geothermal, and wind [81]. In 2013, the main energy consumption in Tanzania comprises of biomass (86%), oil (11%), natural gas (1%), hydro (2%), and the remaining (0.3%) is supplied by coal and other available RE sources (see Figure 12) [82]. The country electricity supply is heavily dependent on hydro, which is not sustainable because of seasonal drought facing some part of the country [81]. Only 18% of the population have accessed to electricity and therefore this calls for the government in investing in RE [81]. Tanzania has already created energy policy since 1992 and since then a number of changes have been made to this policy [83]. In 2003, the policy was reviewed to ensure that energy is used in a sustainable way to fulfill the country's national development goals [83]. Key objectives of the 2003 policy include: (i) promoting the use of RE sources; (ii) encouraging research and development in RE; (iii) creating of enabling atmosphere for RE development; (iv) encouraging private sector participation in RE development, and (v) giving priority to local resources in power generation.

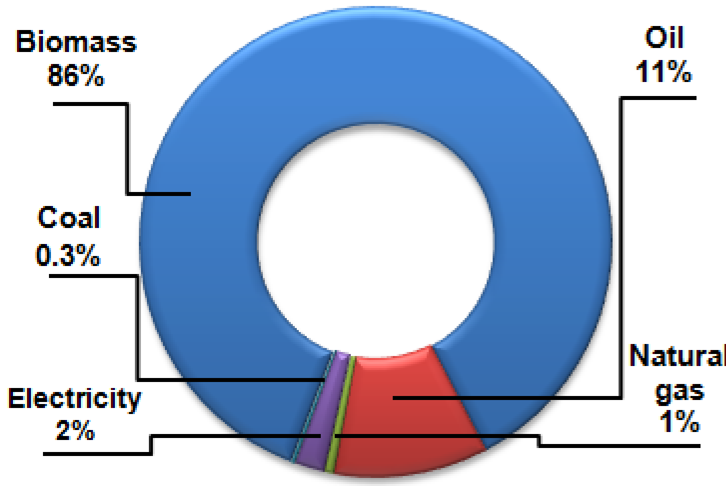

Figure 12: Total primary energy consumption in Tanzania in 2013. Adapted from [82].

The World Bank and The African Development Bank (ADB) has enabled Tanzania to launch a Solar PV Scheme for 70,000 households acrosses rual Tanzania [43]. Climate Investment Funds and ADB have also made available a plan to have small-scale solar installations across 10 rural districts in Tanzania [43].

3.8 Ethiopia

Ethiopia receives solar radiation level ranging from 4.5 kWh/m^2 to 7.5 kWh/m^2 per day [84]. On average, Ethiopia obtained about 6.0 kWh/m^2 /day, corresponding to 2200 kWh/m^2 per year [84]. The average sunshine hours per day in Ethiopia is 6.6 hours [85]. The Ethiopian government in conjunction with the Chinese government prepared wind and solar master plan for the country in order to predict their gross amount and distribution conditions [86]. Based on this study, Ethiopia has a yearly average solar energy reserve of 2.199 million TWh [86]. Ethiopia has an installed solar PV capacity of 5 MW, with approximately 52 MW PV market potential [87].

The indigenous energy sources in Ethiopia are hydro, solar, wind, geothermal and coal [88]. The country's primary energy consumption are biomass 91%, petroleum products (8%) and electricity 1%, [86] as shown in Figure 13. Most of the electricity supply in the country is obtained from hydropower. Ethiopia has already had an energy policy drafted in 1994 [89]. The policy encourages local participation in the development of RE. The Ministry of Water and Energy is responsible for developing and implementing strategies and policies for the energy sector [89]. The policy aims at [89]: (i) promoting the development of RE/alternative energy source and technologies to secure provisions and reduce dependency on fossil energy; (ii) ensuring sustainable and reliable energy at an affordable price, and (iii) ensuring that the utilization of energy is environmentally friendly. Under the "Climate Resilient Green Economy Initiative", the country has aims to install 2.5 GW of RE (including solar) by 2025. There is also a plan by the government to introduce the feed-in tariff proposal [90] and up to 300 MW solar PV projects are being considered in the future [91].

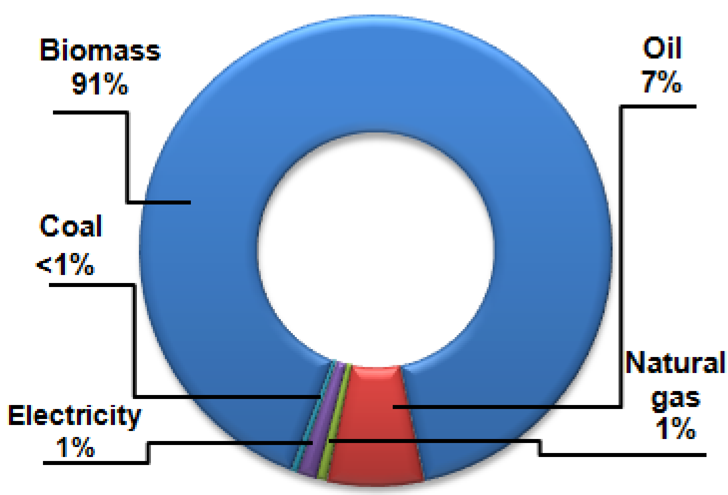

Figure 13: Total primary energy consumption in Ethiopia in 2013. Adapted from [82].

3.9 Angola

Angola's total primary energy consumption in 2013 was contributed by biomass, fossil fuels and electricity, presented in Figure 14. Angola has a potential in harnessing solar energy especially in the energy mix. The solar radiation level in Angola is very high - reaching up to 5 kWh/m^2/day in the capital Luanda [92]. The mean sunshine hours are from 4-5 hours per day during the wet season and 9-10 hours per day during the dry season [93]. The solar energy could be use in schools, health centers, telecommunication, water pumps, and also households [92]. Most of the pilot projects related to solar energy utilized solar PV technology. However, the installed capacity for using solar PV in private households is low [92].

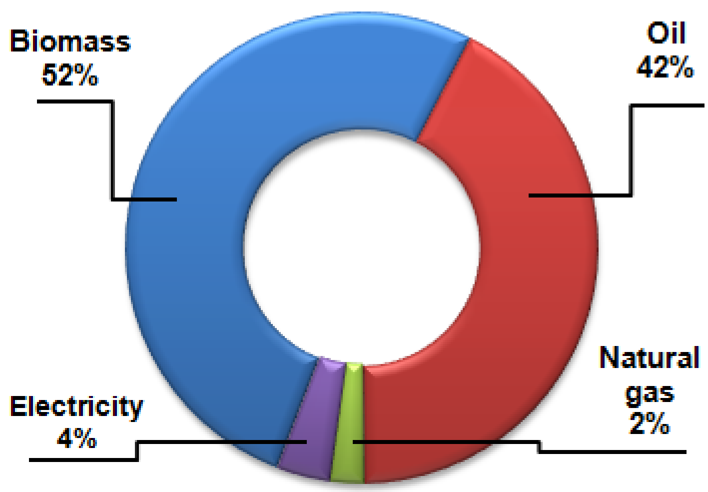

Figure 14: Total primary energy consumption in Angola in 2013. Adapted from [82].

Apart from solar, Angola possesses huge energy potentials such as hydro, wind and biomass. Angola is one of the leading oil producing countries in Africa, but its electricity is largely supplied from hydro. The installed capacity is made up of 76% hydro, 16% gas and 8% thermal [92].

The National Energy and Security Policy of Angola was developed in 2011 [94]. The policy will ensure that the power generating capacity increases to 4.5 times by 2025.

There is a need for incorporation of RE to meet up the energy mix. There is a need for regulatory framework for RE as a vital factor for development. Besides, there is also a need for private sector incentives and necessary stability for investment in RE. This strategy and energy policy aims at producing energy based on sustainable energy technologies that are low-cost and environmental friendly [95].

In 2012, Bloomberg published an article stating that Angola plans to construct up to 130 solar power projects [96]. There is also feasibility study for a PV project of 0.7 MW capacity using 70 grid-connected solar PV [92]. Additionally there is a plan by the government of Angola to install up to 3 MW solar plant in Tombua and other plants in Namibe and Benguela [92].

3.10 Rwanda

Solar Energy has huge potentials in Rwanda. The solar radiation level of Rwanda is from 4.8-5.5kWh/m^2 per day [97]. Sunshine is available in Rwanda for 12 hours in a day for the whole year [98]. Solar PV in Rwanda are used in small scale solar panel to generate off-grid electricity in some community centers and some remote villages. A number of contries have provided the Rwandan government some assistance to realised several PV projects for electrification of rural public units, hospitals, health centers and schools [97]. There is also an on-grid solar PV power plant project with a capacity of 1 MW identified as Kigali solar project [97]. The first stage of this project has been completed on Mount Jali in Kigali with a capacity of about 250 kW and was perceived to be the largest solar power plant in Africa. Currently, the power generation in Rwanda from both hydro and thermal is very minimal [97]. The primary energy source in Rwanda is biomass which account for 86% of the energy demand, while petroleum products consumes 11% and the remaining 3% is consumed by electricity sector (see Figure 15) [99].

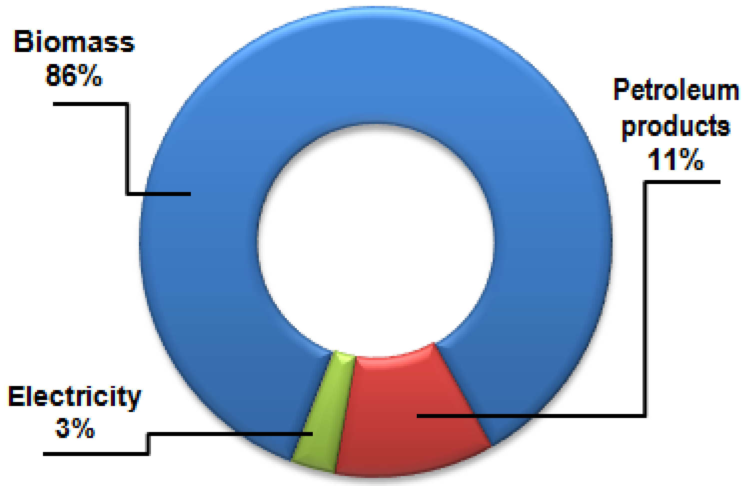

Figure 15: Total primary energy consumption in Rwanda in 2013. Adapted from [99].

Rwanda has already a national policy on energy [99]. The key objectives of the policy are application of local energy sources in the future energy mix, energy conservation and effectiveness, regulatory framework, capacity building in RE, private sector involvement and investment from the financial sector.

The government of Rwanda has already alocated land for solar park enhancement, and a feed-in tariff scheme for solar is presently being developed. A utility solar PV plant of up to 8.5 MW has already being completed and more projects are on the pipeline [100]. These include a 250 kW Solaire PV and 30 kW Nelson Mandela EC [100].

4. Conclusions, bariers and recommendations for future improvement

From the review carried out in this paper, it is obvious that sub-Saharan African countries have huge RE potentials. Most of these developing countries have similar weather conditions. In terms of solar energy, the progress made in solar PV in sub-Saharan African countries is growing at a 'slow pace' as compared to the other parts of the world.

However, this review could provide useful information for the policy makers, private institutions and government organizations in oder to understand the PV systems situation in this region. Table 3 presents the development made by these countries with regards to the solar PV. From this table, it is obvious that South Africa has the highest installed capacity, while Cameroon appears to be the lowest installation of less than 1 MW and no clear policy on RE. However, it is important to note that most of these countries have considered solar energy as one of the important sources for future sustainable energy. To date, only three countries have implemented the feed-in tariff scheme namely Ghana, South Africa and Kenya, while others have included the feed-in tariff implementation in their future energy plan. The three countries have already connected part of their solar PV into their national grids.

The review on the solar PV progress in Sub-Saharan Africa as presented in this paper indicates that there are improvements that can be made as far as solar PV development and implementation is concerned. The bariers and recommendations for scaling up RE in these countries are as follows:

1) Energy policy implementation
    - Though most of the countries have identified the importance of RE and in particular solar energy as a solution to their current electricity crisis, there is slow implementation of the supportive policies. This is caused by inadequate research and development, insufficient funding instruments and lack of technical capabilities. There is also lack of political will from the government to pursue energy policy implementation. Besides that, there is lack of budgetry allocations or dedicated funds for RE promotion and lack of enforcement mechanisms in those countries.

    - There is also limited scope of the energy infrastructure for the geographical users. For these policies to be fully implemented, there should be less reliance upon government controlled monopoly and private sector initiatives should be considered. There should be an enabling environment to encourage local enterpreneurship in the sector.

- To accelerate the solar PV development policies, the feed-in tariff system must be implemented in the remaining sub-Saharan African countries. A number of countries in Europe (the UK, Spain, Germany) [101] and Asian countries (Malysia, Thailand and Indonesia) [11,102] have already implemented a functional feed-in tariff system which the sub-Saharan African countries can learn from.

2) Lack of technical capability and information

- Most of the sub-Saharan African countries do not have accurate solar resource data. The available ones are not related to the state of art techniques such as satellites. There is also insufficient technical expertise in that region to accelerate solar PV developments.
- There is also lack of local technical skills in national institution for technical manpower in collaboration with the private sectors. This will enhance bussiness, manufacturing and overall RE management. The government should put in place effective monitoring and evaluation strategies to develop solar PV technology.

3) Investment and Financing

- Most of the sub-Saharan African countries face serious challenges in order to source funding for RE especially solar PV. Currently, the economy in Africa is not doing well due to the on going financial crisis. As a result of the improper governmnet support, the private sectors are not willing to invest in RE. Most of the private sector finance is non-local i.e coming from international financing organizations. The governments should encourage local private sectors to collaborate with their international counterparts in RE especially solar PV projects. This requires transparency management of the scarce resources leadership and good governance.
- There is also improper marketing of the solar PV products in some countries. Lack of appropriate media for RE advertisement also affects

marketing of these technologies. The governments in these countries should work on finding suitable media for dissemenating information and awareness regarding the benefits of RE.

4) Connection of the Solar energy infrastructure to the national grid

- Most of the sub-Saharan African countries have not connected the solar PV stations to the country’s grid. This may be due to lack of expertise to carry out this task. The government should encourage local professionals to carry out feasibility studies and assessments on on-grid solar PV in these countries. The high capital cost of installation of on-grid solar PV together with the cost of maintainance may be the likely cause of non-connection of solar PV stations to the grid.

Table 3: Summary of solar PV development in sub-saharan Africa.

Country	Installed capacity	Solar Energy target share in total installed capacity	Primary RE	Maximum Solar radiation	Policies related to RE	Feed-in tariff rate for solar
Nigeria	15MW	5% by the year 2020	Biomass (80%), oil (13%), natural gas (6%), hydro (1%).	7.0 $kWh/m^2/day$	Nigerias's National Energy Policy (2003)	N/A
Cameroon	Less than 1 MW	0%	Biomass (64%), oil (27%), hydro (5%), natural gas (4%).	5.8 kWh/m^2 /day	No energy policy available to the public.	N/A
Ghana	3.8 MW	10% all renewables including solar by2020	Wood (42%), oil (47%), hydro (8%), natural gas (3%)	5.0 $kWh/hr/m^2/day$	RE Act (2011)	GHS0.5836/kWh (USD0.153/kWh) - without grid connection and GHS0.64/kWh (USD0.168/kWh) with grid connection
South Africa	36.5 MW	21% including 1.5 GW of solar	Coal (72%), oil (22%), natural	6.5 $kWh/m^2/day$	White paper (1998 and 2003).	ZAR 3.94/kWh (2009)

		capacity by 2021.	gas (3%), nuclear (3%), renewables (<1%)			
Kenya	1.3 MW on grid	6%	Biomass (68%), oil (22%), hydro (8%), coal (1%)	6.0 kWh/m^2/day	National policy (2004)	USD 0.12/kWh for 0.5 MW up to 40 MW
Senegal	25 MW	15% all renewables including solar by 2020	Biomass (54%), oil (40%), hydro and coal (6%)	5.5 kWh/m^2/day	Electricity Reform Law (1998)	N/A
Tanzania	6 MW	10% of other sources including solar by 2020.	Biomass (86%), oil (11%), electricity (2%), natural gas (2%), coal (0.3%)	7.0 kWh/m^2/day	RE policy(2003)	N/A
Ethiopia	5 MW	15%- all renewables including solar by2020.	Biomass (91%), oil (7%), electricity (1%), natural gas (1%), coal (<1%)	7.5 kWh/m^2/day	Energy policy(1994)	N/A
Angola	5 kW	Not available in the policy	Biomass (52%), oil (42%),	5.0 kWh/m^2/day	National energy and security policy	N/A

			electricity (4%), natural gas (2%)		(2011)	
Rwanda	250 kW	2% in the future energy mix	Biomass (86%), petroleum products (11%), electricity 3(%)	5.5 kWh/m^2/ day	National energy policy (2008)	N/A

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