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A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria

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ABSTRACT

Despite its vast natural resources, African is facing serious challenges in sustainable development in an energy sector, if addressed with dispatch could not only check its indispensable needs, but also mitigate some global phenomenon at stake, such as desertification, environmental degradation and green house emission. This paper reviews the prospects of four major renewable energy sources-hydro, solar, wind and biomass- for each of the three leading countries in Africa namely South Africa, Egypt and Nigeria. Based on literature survey of energy efficiency, all the three countries encourage energy efficiency in varying degrees. In the course of this review, several national energy policy frameworks of these countries were looked into, especially on how African countries could overcome the persistent energy crisis in the continent by utilizing the naturally gifted renewable energy sources. This could only be achievable if proper technology, awareness and skills for harnessing the resources are provided. Also lingering energy challenges such as energy efficiency measures, needs for grid extension, energy storage technology and seasonal variation were carefully highlighted.

1. Introduction

Investigation has shown that renewable energy sources such as power from sun (photovoltaic and solar thermal), hydro, wind and biomass-derived fuel have contributed greatly to the sustainability of certain nations with several environmental and socioeconomic benefits to the nations that tap them. A far bigger and wider benefit according to research, is the contribution of renewable energy in the reduction of pollution at both local and global levels, thus helping in the mitigation of climatic change which both industrialized and developing nations committed themselves to in the Kyoto protocol. It has been tested and proven that reliable and affordable power supply is an essential prerequisite for technological and economic growth. Generation of electricity from renewable energy resources can play a major role in electricity generation in African countries.

This paper presents a review of renewable energy technological development in South Africa, Egypt and Nigeria which varies due to factors that included topography, characteristics of the resource, cost of labor and policy regulation. The three countries have about half of the total of Africa's primary energy use as shown in Fig. 1 [1], - a status that can translate into huge economic growth if power supply is reliable and affordable.

In his review of renewable energy for sustainable development in Africa, I.M. Bugaje considered the extent to which policies on solar, wind, biomass and biogas are meeting up top challenges of sustainable development in four countries namely South Africa, Nigeria, Mali and Egypt [2]. In a paper titled "the economics of renewable energy expansion in rural sub-Saharan Africa", Uwe Deichman chose Ethiopia, Ghana and Kenya [3]. In his short review that focused on poverty and energy in Africa, Stephen Karekezi talked about population, energy consumption, renewable energy, fossil fuel and access to electricity [4]. In his another paper titled "renewable in Africa- meeting the energy needs of the poor", Karekezi examined the large and small-scale biomass energy, solar PV, solar thermal, evaluates how each of the renewable energy technologies can meet the need of rural and urban poor [5].

In view of the absence of a paper that focuses on the three leading nations namely South Africa, Egypt and Nigeria, this paper has made an extensive review of the four major renewable energy sources (hydro, solar, wind and biomass), energy efficiency of each of the three countries, energy policy, overview of conventional energy, why renewable energy?, strategies towards utilization of energy efficiency in Africa, renewable energy road map in Africa, needs for grid extension, energy storage system and seasonal variations in Africa.

This review paper starts with an introduction, followed by the overview of conventional energy in Africa, why renewable energy?, strategies towards utilization of efficient energy in Africa, an extensive review of the four major renewable energy sources, energy efficiency of

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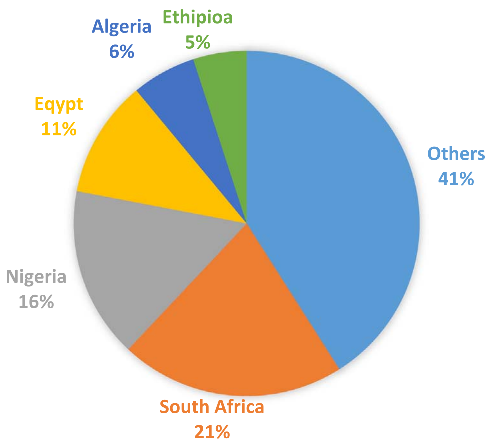

Fig. 1. primary energy use in Africa by country, 2009 [1].

each of the case studies starting with South Africa, Egypt and Nigeria, renewable energy road map for Africa, energy policy in Africa, energy storage systems, general discussion and finally ends with the conclusion.

2. Conventional energy in Africa

With proven oil reserve which increased by 150% from 53.4 billion barrels in 1980 to 13.3 billion barrels as of 2013 (according to BP Statistical Review of Energy), Africa is second only to the Middle East in terms of oil export and it accounts for over 11% of world oil production. However, the bulk of the oil is exported as the continent accounts for only 4% of global oil consumption. Since 2013 Africa's oil export has declined from an average of 6.3million bpd to 5.2 million bpd as a result of sharp drop in Libya's output and low production from Nigeria, Algeria and Sudan. The four countries account for 84% of Africa's oil production (Libya 48.5 billion barrels reserve, Nigeria- 37.1 billion barrels reserve, Angola- 12.7 billion barrels reserve and Algeria- 12.2 billion barrel) and are all members of the Organization of Petroleum Exporting Countries (OPEC), Figs. 2 and 3 show chart representing Africa's oil and gas reserve as well as the production (in million bpd).

Africa's natural gas proven reserve significantly increased between mid-1980 to early 2000s, due to mainly a strong increase in Nigerian reserves. West African contributed almost half of the total natural gas proven reserve increment over a period of mid-1980 to early 2000s, while the North Africa which consists of Libya, Algeria and Egypt accounted for the remaining. As at the beginning of 2014, five countries accounted for 94.4% of the total of Africa's natural gas reserves. The countries are Nigeria (5.1 trillion m^3), Libya, Algeria and Egypt combined (8.1 trillion m^3) while Mozambique whose proven gas rose from 126 billion m^3 to 2.8 trillion m^3 from 2013 to 2014 [6–9]. Table 1 represent the non-renewable energy potential of Africa.

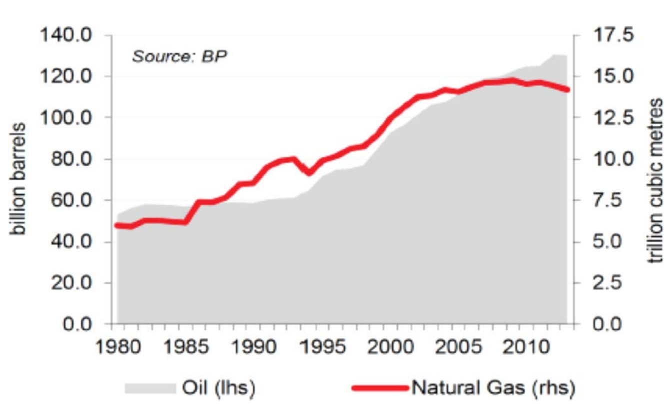

Fig. 2. Africa's proven oil and gas reserve [6].

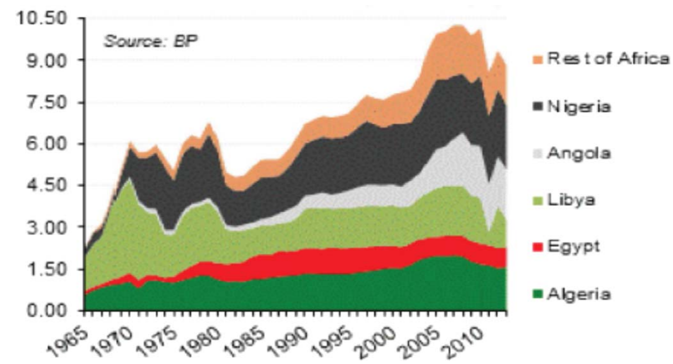

Fig. 3. Africa oil production (million bpd) [6].

Table 1
Non-renewable energy resources potential of Africa [7].

Types energy	Proven reserves	Regional distribution
Non-renewable		
Crude oil	132.1 billion barrels	53.2% Northern Africa 28.2% Western Africa 16.9% Central Africa 1.7% Other Africa
Natural gas	14.7 trillion m^3	55.8% Northern Africa 36.1% Western Africa 8.2% Other Africa
Coal	31.696 billion tones	95.2% Southern Africa 4.8% Other Africa
Nuclear	Reasonably assured resources: 663,400 tones	2.9% Northern Africa 36.7% Western Africa
	Inferred resources: 286,300 tones	2.7% Central Africa 4.2% Eastern Africa 53.5% Southern Africa

3. Why renewable energy

The united nations has regarded Africa as one of the continents with maximum vulnerability to the effects of climatic change due to population growth and its attendant human activities, overreliance on subsistence agric, low capacity to adapt to change and impending water crises. Whereas the quest for renewable energy in developed countries driven more by insecurity in energy supply, air pollution caused by burning fossil fuel, the need for resource diversification and prospect of resource depletion, Africa remains vulnerable to vagaries of fossil fuel set to developed countries to which they export crude oil [10–12].

Renewable energy as an alternative is a sustainable option that can significantly overdependence on fossil fuel. Furthermore it has the advantage of creating employment, proximity to load and in many cases, led dependence on concentrated energy source. The use of more renewable energy would similarly reduce Africa's economic vulnerability to the adjustable and rising prices of imported fuels. Global and local communities are gradually trying to follow the renewable energy trend by shifting the economy towards greater dependence on renewable source. It is expected that rules and regulations, as well as voluntary structures such as the "Clean Development Mechanism" and Renewable Energy Certificates will offer better sustenance for a prolonged role of renewable energy in the economy [13].

Table 2 shows the renewable energy target of Egypt, Nigeria and South Africa, and Table 3 shows electricity access, population without access and targets access of Egypt, Nigeria and South Africa.

4. Strategies toward utilization of efficient energy in Africa

For an energy need to be attained by all and sundry, proper

Table 2
Renewable energy targets for Egypt, Nigeria and South Africa [14].

Country	Sector/Technology	Targets
Egypt	Hydropower	2.8 GW by 2020
	Solar PV	220 MW by 202; 700 MW by 2027
	CSP	1.1 GW by 2020; 2.8 GW by 2017
	Wind power	12% of generation and 7.2 GW by 2020
Nigeria	Bio power	50 MW by 2015; 400 MW by 2025
	Hydropower (small scale)	600 MW by 2015; 2 GW by 2025
	Solar PV (Large scale > 1 MW)	75 MW by 2015; 500 MW by 2025
	Wind power	20 MW by 2015; 40 MW by 2025
	CSP	1 MW by 2015; 5 MW by 2025
South Africa	(Electricity)	(18.2 GW by 2030; 42% of new generation capacity installed 2010–2030)
	Solar PV	8.4 GW by 2030
	Wind	8.4 GW by 2030
	CSP	1 GW by 2030
	Others	0.4 GW by 2030 [15].

Table 3
Electricity access by country (Egypt, Nigeria and South Africa) [14].

Country	Electrification rate in 2012	People without access to electricity in 2012	Targets
	Share of population with access	millions	Share of population with access
Egypt	99.6%	0	
Nigeria	45%	93	75% by 2020
South Africa	85%	8	100% by 2019

strategies of energy management need to be addressed at various sectors such as residential, commercial and industrial [16]. Energy management can be defined as the strategies of shifting or optimizing the use of energy. The main purpose of energy managements are; conservation of resources, climatic protection and energy cost saving [17]. Energy efficiency is the act of replacing electrical equipments with the less energy consumption equipments with the same output magnitude. There is need to identify the inefficient energy equipments and find a solutions, so as to improve the efficiency of the power sector. However, ongoing monitoring and target need to be schedule in order to measure their performance [16].

Improvement of energy efficiency is the cheapest, fastest and environmental friendly way to meet a significant of the world's energy demand. The need for energy investment is reduced by energy efficiency which is more economical because in the end, it reduces energy cost overtime. Energy efficiency is associated with technical and cost obstacles that are subordinate to other barriers, these include; financing, creating awareness, incentives, public acceptance and proper education. Countries are encouraged to pursue energy efficient policies more patiently in the long term period regardless of the development of the fuel prices. Energy efficiency and renewable energy policies are very vital because of their advantage - for providing energy security and mitigation of global warming [18].

To improve energy efficiency significantly, government should employ regulations and standards such as public sector leadership in procurement, public awareness and incentives. The points below are the strategies towards utilizing energy efficiency in Africa.

a) The use of buildings with insulated windows, modern oil and gas furnace and efficient air conditioners, replacement of incandescent lamps with the compact fluorescent lamps, can result to 30–60% energy saving cost.
b) Industrial sector: the use of improved efficient pumps, boilers, motors, heating system and other material with high efficiency can reduce energy demand and greenhouse gases.
c) Transportation sector: the use of efficient diesel and gas vehicle and other method of transportations.
d) Residential sector: major improvements have been made in refrigerators, water heaters, washing machines and dish washers. Advance technologies such as smart metering, micro combine heat and power generation CHP, fuel cells, solar photovoltaic and more efficiency lighting can save energy [18].
e) Demand side management (DSM) and energy conservation measures (ECM): DSM is an action or policies or program tends to reduce managing the energy consumption. DSM give birth to three programs; energy efficiency, energy conservation measures and load management. Energy conservation measures ECM is to change the consumption of energy by the consumers based on shifting their peak period energy consumption to the base period. Or the method of valley filling etc. utilities should encourage the consumers by giving incentives on less consumption of energy and enlighten the consumers on the importance of energy efficient equipment's.
f) Installation of electrical equipments control: electrical equipments control such as lighting control, street light control, electric water heater control etc. can be used to turn off or on or dimming them based on the energy output required. It makes the system flexible such that the consumption of energy can be controlled based on the usage of energy at a particular time.

The importance of energy efficiency are outlined into eight points, which are; (i) It improve the health of the nation, i.e. reduce the emission of harmful gases into the atmosphere. Such gases have an adverse effect on health, such as respiratory ailments, cancer etc. (ii) Alleviates energy poverty i.e. it alleviates energy services in the environment at an affordable cost. (iii) Reduction of environmental pollution such as emission of harmful odorous gases. (iv) Improves industrial competitiveness i.e. it has been proven that, one way to maximize profit in an industries is to implement energy efficiency measures. (v) Enhances energy security i.e. it will reduce the imported sources into the country such as crude oil, coal etc., this will strength the energy security of the country against price fluctuation of the products. (vi) Defers the necessity for additional power generation capacity. (vii) The country power generation is insufficient to meet the consumer demand. But with energy efficiency measures it will maximize the demand. (viii) Job creation and lastly Reduce of CO2 emission [16].

Demand side energy efficiency enhancement determines obviously the costs of energy for end-users, while for supply side energy efficiency i.e. (generation, transmission and distribution) employed by the utility firms will also result into cost benefits for end users by ensuring energy prices are well controlled. It will ensure older systems and equipment of the power system to be in good conditions because of lesser total loads which enable the operation of equipment below the maximum capacity [19].

Over 60% of urban population in Africa do not get adequate electricity. They depend on tradition energy i.e. wood for cooking and much is spend for the purpose of energy services such as kerosene and electricity compare to other countries. It is estimated that the energy used in African homes consumed 56% of the entire national electricity. In large cities, the consumption is more than 75% of the whole electricity produced and the urban energy demand increases annually by 7%. The initiative of the UN secretary general Ban Ki-moon on “sustainable energy for all” pleaded for players to join hands and efforts to; ensure the accessibility of modern energy services universally by 2030, doubling the rate of improving in energy efficiency, doubling energy efficiency improvement and the share of renewable energy in the mix of global energy [20].

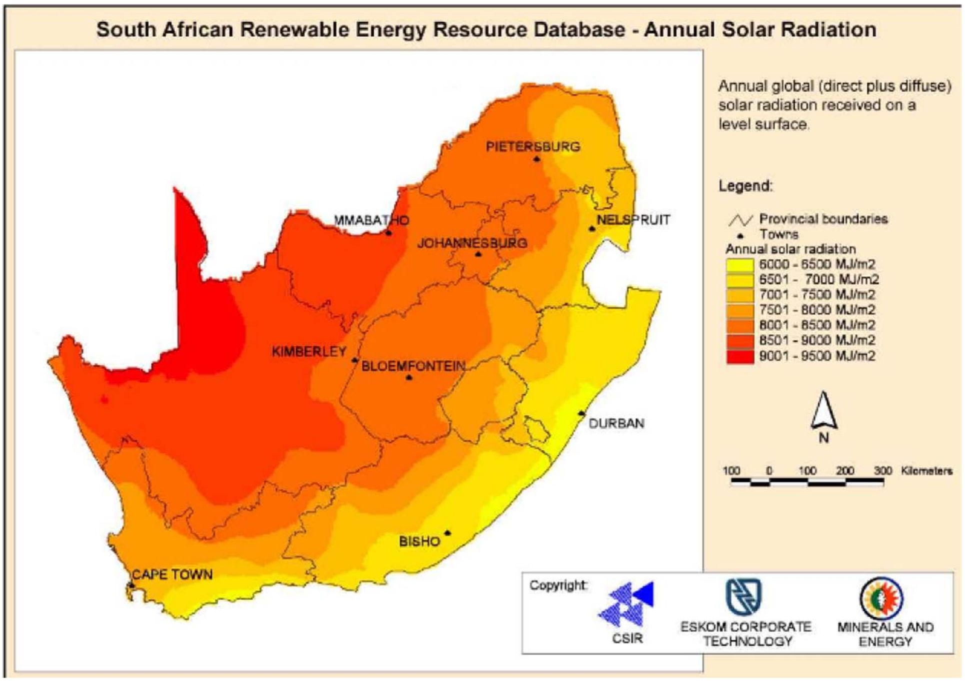

Fig. 4. Annual solar radiation of South Africa [12] *Source CSIR et al., a.s.*

The scope of increasing energy efficiency from the supply side and reduction of energy consumption at the demand side without economic output and reducing standard of living is significant in African countries. Based on International Energy Agency (IEA) studies, shows that, the African total energy consumption per GDP is twice the global average. Energy efficiency has been greatly pursued in North Africa, South Africa and a few countries in sub-Saharan Africa. The obstacles that hindered the adoption of energy efficiency programs are; initial capital cost, lack of appreciation, resistance to change, lack of policies-regulatory frameworks and subsidy of cost of energy.

To ensure economic competitiveness, Africa needs to systematically incorporate energy efficiency into the existing energy generation and use system as well as new major infrastructure projects. This could be achieved through the formation of policy and regulatory frameworks that would promote energy efficiency with appropriate policy instruments to ensure success and effectiveness.

Energy efficiency provides several benefits to Africa, as it reduce carbon mono-oxide and other greenhouse gas emission. Thus, reducing the burning of fossil fuels will address the issue of climatic change as such accelerate the use of renewable energy sources and more efficient technologies which provide "win-win" options to tackle global and local challenges. Over 75% capacity of power generation in Africa is based on thermal energy, as such improving energy efficiency in the existing systems could results to a significant money savings by many countries and will increase competition among the local industries [21].

5. South Africa

The southernmost country in Africa is South Africa as it is circumscribed by south Atlantic, and Indian Ocean on the north by the neighboring countries of Namibia, Botswana and Zimbabwe, by Mozambique and Swaziland from the eastern and northern part respectively, and surrounding the kingdom of Lesotho. The 25th largest country in the world by land zone and a population of closed to 53 million people [22]. South Africa figured out the commencement of a speedy transition towards renewable energy, and came up with a renewable energy policy in 2003. The Renewable Energy White Paper (REWP 2003), developed by the Department of Minerals and Energy, set a target for renewable energy contribution, over and above the existing renewable energy contribution. The REWP 2003 also dedicated the country to developing a practical strategy application on renewable energy. The renewable energy resources of South Africa have large and vital potential that will contribute immensely to its energy sector, society and the economy at large. The cost of energy is an important factor in determining the cost effectiveness of renewable energy technologies [13].

5.1. Hydropower

Hydropower is indirectly another form of solar energy. The vapor cycle as result of the sun give rise to rain and eventually transform to a rivers which are used to generate hydroelectricity. Topography via which the flow of rivers occur normally determines the energy from hydro resources [12].

According to international standard, the widespread deployment of hydropower electricity generation has not received serious attention in South Africa. For the past three decades, the significant of hydropower development has not been recorded excepting for the new small-scale installation of 7 MW capability commissioned at the Sol Plaatjie municipality Free State area. Currently, the overall penetration of hydropower electricity is only 5% of the present total of 45,500 MW installed capacity [23].

5.2. Solar

Solar energy is one of the renewable energy resources with highest potential in South Africa. The popularly known technologies used to produce electrical energy from solar radiation are; photovoltaic (PV) and concentrated solar power (CSP) also called solar thermal energy. In this process, CSP plants use mirrors to concentrate the energy from the sun to drive traditional steam turbines or engines that create electricity. Steam produce by the heat energy is then used to generate energy through the conventional turbine. Silicon is used in photovoltaic panels to convert solar radiation into electrical energy directly [13]. The major shortcoming of electricity generated from solar is storage problem, in an off-grid configuration, the storage technology involves a significant running cost as a result of it limited life span. However, technologies like fuel cell, super capacitors, flywheel and enhanced chemical batteries were used to decrease the running cost considerably provide more hope. The grid connected system is the main international market for photovoltaic which uses the grid system as its storage alongside with dispersed storage option [12].

Fig. 4 indicates the potentials of solar energy resources in South Africa. There is a total area of approximately 194,000 km^2 of high solar radiation potential including Northern Cape which is one of the best solar resource area in the world. Note that 1300 MJ/m^2/year is equal to 1 kW h/m^2/day.

Photovoltaic (PV) has been widely in used in South Africa for the purpose of lighting, home appliances, telecommunication, water pumps in homes and institutions in the rural areas. The price of the photovoltaic module used to be expensive but is now declining steadily over the past decade. In the developments described, it was envisioned that PV technology will be playing a very significant part up to 14 per cent in supply by the year 2050 [12].

5.3. Wind

Wind is indirectly connected with solar energy, due to the fact that the energy from the sun drives the climate pattern and cyclical movement of water vapor and air. Much parts of South Africa is in the equatorial zone but also overlaps with wind regime of the temperate westerlies in the southern and northern region. Having identified as one of the country with greatest wind prospect in the sub-Saharan Africa, it has a wind speed ranging from 7.29 to 9.70 m/s recorded in Cape Alguhas through Cape point. Although there is no record of mean annual wind speed across the country, perhaps due to variations, general use of wind machines in many parts of the country for the purpose of pumping water points to the potential of wind power even for electricity generation [5] (Fig. 5 shows the current wind atlas which is compiled from modelling that was done under two separate projects in South Africa).

Although studies have put South Africa's potential for wind energy between a minimum of 500 MW, and maximum of 56,000 MW, only 0.05% has been generated from the ESKOM Klipheuwel demonstration plant and the Darling wind farm. A number of small turbines have also been mounted on locations along, but not connected to the national grid [12,20].

5.4. Biomass

The status of biomass will continue to increase in as much as the national energy policies and strategies are following the trend of renewable energy sources. In recent years, biomass energy source has gained specific interest as a result of the progressive reduction of conventional fossil fuel that led to an increase in the use of renewable energy sources [25].

The level of power generation from biomass is significant in South Africa, some of the paper packaging and sugar mills burn bagasse using biomass to generate steam, generate roughly 210 GWh of electricity each year. Biomass being considered as renewable which is free from carbon has its own downside environmentally, few among others are as follows;

a) Level of water: Water shortage still remains one of the problems encountered by South Africa
b) Food security: famers should give emphasis to food crop not only energy crop in other to avoid food scarcity.
c) Biodiversity: planting of single energy crop in large scale also has to some extent effect on land quality.

The areas with greatest biomass energy in South Africa are Kwazulu-Natal and the water ways of Mpumalanga. Presently, there are about 4300 km^2ha of sugar cane plantation and forestry farm area of 13,000 km^2 in South Africa. The paper and bagasse burnt by sugar mill produces about 210 GW h annually [12].

5.5. Energy efficiency in South Africa

Improving energy efficient technologies and renewable energy sources are very important for the sustainable development of any country. Since 1998, the Government of South Africa set up a demand side management, energy efficiency measures and strategies in policy documents. The current drafted policy was National climate change response white paper of 2011, energy efficiency was highlighted as one of its main goal. Energy efficiency measures and strategies are also included in the national energy Act 34 of 2008 and the electricity regulation Act 4 of 2006. Its National Standards SANS 50001:2011

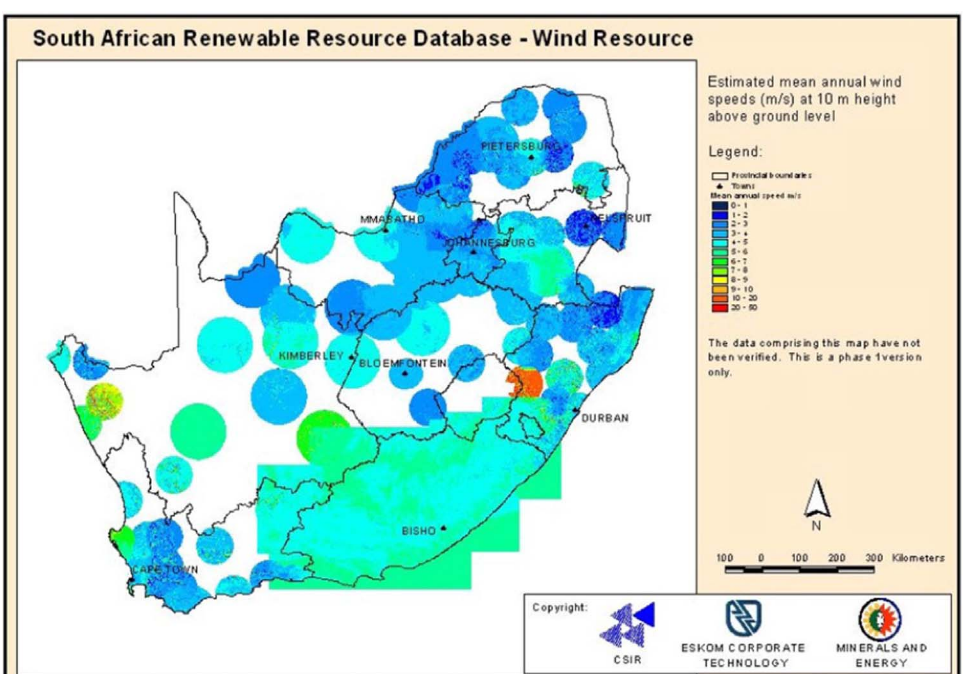

Fig. 5. Current Wind Atlas for South Africa [24].

Table 4
South African end users electricity consumption by sectors [26].

Sector	% (Percentage)
Domestic	17.2
Agriculture	2.6
Mining	15
Industries	37.7
Commerce	12.6
Transport	2.6
Others	12.3

were published in July 2011 with the aim of improving energy management (EnMS) standards through energy performance, energy efficiency, and consumption uses and pattern of a building. The standard lead to two important factors, first, reduction in greenhouse gas emission and other environmental impacts and secondly, reduction of energy cost through the energy programs mentioned.

South Africa has the capacity of energy efficiency of 20–30% across various sectors as stated by the Department of Energy in 2010. The end users electricity consumption in the country is depicted in Table 4.

International energy association IEA introduced 25 energy efficiency recommendation in 2011 upon which South Africa is not a member and some of the recommendations are; industries should be reporting their energy saving, energy management measures etc. [26]. In South Africa, there is a program named EEDSM. Its main function is to develop and implement energy efficiency measures, by public awareness, understanding the energy efficiency and implementation of incentives for the participates of energy efficiency [27].

In 2008, the major reorganizations have led to new legislation and entities to govern and implement energy efficiency in South Africa. In 2009 the department of minerals and energy divided into two and becomes department of mineral resources and department of energy. However, the department of energy drafted the energy efficiency policy under the authority of national energy Act. Also, department of trade and industry serves as an actor in implementing for energy efficiency policy especially standard and labelling (S & L). In 2008 energy Act established the South Africa national energy development institute (SANEDI) aimed to conduct public interest energy research.

The South African government introduced an allowances for energy efficiency via section 12I and section 12L.

a) The 12I incentive is designed to support cleaner production investment in manufacturing expansion.
b) The 12L gives an allowances for energy saving achieved through energy efficiency. In has not been effective.

The key measures implemented by the South African government to support energy efficiency include the public sector, manufacturing sector, building codes, energy efficiency management and carbon tax [28].

6. Egypt

The republic of Egypt is situated in North Africa, bordered by Libya in the east, Sudan in the south, Palestine and Israel in the east [29]. Egypt is blessed with tremendous potentials of renewable energy resources such as wind, solar, hydro, biomass etc. It has a population of more than 83 million people, mainly concentrated along the river Nile and occupies only 6% of the land and 94% of the land as a desert. Based on international energy agency IEA state that, the energy consumption of Egypt by end user was 47% for industry, 29% of transport, 20% for buildings, 2% in agriculture and 2% for other sectors [30]. New and renewable energy authority was established in 1986 through the aim of assessing and promoting renewable energy sources through research and investigation of new technologies. They also have testing laboratories and certifications, and carried out the training programs [31]. In 2012, renewable energy sources contribute 14,855 GW h electricity production. 13,358 GW h was produced by hydropower, wind energy contributes 1260 GW h and solar PV contributes 237 GW h [29]. The Egypt ministry of electricity has announced feed-in-tariff for electricity generated by solar and wind sources as part of the government effort to encourage renewable energy and improve the electricity shortage. Table 5 shows the feed-in- tariff categories in Egypt.

Table 5
Feed-in-tariff categories in Egypt [32].

FiTs	Capacity
$0.117/kW h	< 10 kW
$0.125/kW h	< 200 kW
$0.136/kW h	200–500 kW
$0.136/kW h	500 kW to 20 MW
$0.143/kW h	20–50 MW

6.1. Hydropower

Hydropower contribute 12% of Egypt electricity production in 2009. The hydropower capacity in Egypt is about 3664 MW with an estimated energy of 15,300 GWh/annum. Presently, there are five main hydropower generation locations, which are situated on the river Nile [31]. The five main hydropower plants are: Aswan I, Esna, Aswan II, Naga Hamadi and High Dam with installed capacity of 280 MW, 85.68 MW, 270 MW, 64 MW and 2100 MW respectively. There are also small/mini hydropower potential in Egypt. Table 6 shows the site, head (m), flow (m^3/sec) and power (MW) of the small/mini hydropower potential [33].

The Aswan high is shown in Fig. 6.

6.2. Solar

Egypt is a country with rich solar energy. It is among the global Sun Belt. In 1991 solar atlas for Egypt showed that the annual sunshine hours is 2900–3200 h with an annual direct energy density as 1970–3200 kW h/m^2, and the technical solar thermal electricity generating potential of 73.6 Petawatt (pW h) [35]. Fig. 9 shows the atlas of solar irradiance in Egypt.

Egypt has high energy intensity that reaches 7.2 kW h/m^2 days in some southern part of the country. Solar energy in Egypt is well spread over the country and not concentrated in some areas and it is more stable and it is more predictable than the wind energy [37]. The Egypt government received a bids from local and international privates companies for the implementation of 20 projects for the generation of solar energy at the cost of 30 billion dollars with the capacity of 20,000 MW to the electricity grid in just two years [38]. The first solar thermal power plant with the power rating of 140 MW, was started in

Table 6
Small/mini hydropower potential in Egypt [33].

Site	Head (m)	Flow (m^3/sec)	Power (MW)
Assuit barrage	3.5	1200	32
Damietta	4	350	13
Zefta	5	150	5
Elmokhtalet	20.75	5	1
Tawfike rayah	1.86	134	2.45
Assuit regulator	1.33	229	3
Ibrahimia canal intake	1.38	114	1.55
Baheri Raya	1.2	188	2.2
Menoufi Raya	1	173	1.8
Sharkawia Canal	0.82	232	1.85
Total			63.55

Fig. 6. Aswan high dam in Egypt [34].

January 2008 and plan to be accomplished in 2010 [39]. In September 2014, Ministry of Electricity and Renewable Energy target to generate 2300 MW using solar PV. It comprised of 300 MW of projects below 500 kW, and 2000 kW for projects between 500 kW and 50 MW [40].

6.3. Wind

Power generation in Egypt is mainly by fossil fuels and hydropower. Egypt has an abundant energy resources. Wind is among the resources that is in abundant and sufficient to generate a reasonable amount of electricity [41]. New and Renewable Energy Authority (NREA) in collaboration with Riseo National lab has done a tremendous work on the art of wind atlas where they classified the regions based on speed and the turbine hub. According to NREA the mean speed ranges between 8 m/s and 10.5 m/s at 25 m in Red sea coast of Egypt. Perhaps, based on the wind atlas, Table 7 shows the major areas where wind energy resources is sufficient.

However, from the wind atlas in Fig. 7, at hub height of 50 m above the surface shows, the area that are Red, pink, purple and yellow have a power density of 400 W/m^2, 500 W/m^2, 600 W/m^2, 300–400 W/m^2 respectively [42].

A resolution on a plan to cover 20% of electricity generation by renewable energy sources by 2020 was adopted by the Supreme council of energy in Egypt. Perhaps, wind energy will contribute 12% of the energy. Zafarana wind farm is the largest of its kind in Africa, that can generate 545 MW and also gulf of El-zeyt generate 200 MW as shown in Table 8 [43].

The Zafarana 8 wind power farm is shown in Fig. 8.

6.4. Biomass

Egypt has a target of generating 20% using renewable energy sources by the year 2020. Egypt has a great potential of biomass sources. The main biomass sources are agricultural residues (crop residues) followed by municipal solid wastes, animal waste and sewage waste All these sources are presently used inefficiently, especially agricultural residues which are been combusted in an open fire stove in villages. Biomass sources can be used to generate a huge amount of energy by proper utilization of the sources. Agricultural residues are the amount of crops that remain after removal of the useful product. Egypt yield a crop two to three times a year. In 2003 over 27 million of crop residue were generated. Huge amount of animal waste are also produced in Egypt, but it depends on the type of animal, size and the population density of each location. Municipal solid wastes estimated to be 15.3 million tons in 2001 of which 75% were generated in the urban areas. Sewage waste, an estimate of 2 million tons/year of dry sludge were produced in 2008. All these sources can generate a large amount of electricity which is clean [46].

Table 7
Wind resource areas in Egypt [42].

Area	Power density (w/m^2)
Gulf of Suez	400–600 W/m^2
Gulf of Aqaba	400–600 W/m^2
Western Egypt domain at the west bank of the Nile	300–400 W/m^2
Eastern Egypt domain at the east bank of the Nile	300 W/m^2
Western desert area close to Kharja	300–400 W/m^2

The potential of biomass sources in Egypt is very huge, although limited work have been done for electricity generation. The main crop residues are agricultural waste such as crop residues from wheat, maize, rice and sugar cane. Based on the research study by Suzan Abdelhady et al. (ICAE2014) stated that the un-utilized amount of rice straw of 3.1 million tons/year can generate 2477 GW h/year of electric energy. According to FOA (Food and Agriculture Organization) that Egypt is the largest producer of rice in Africa as shown in Table 9 [47].

6.5. Energy efficiency in Egypt

The energy sector in Egypt is handled through two ministries, the Ministry of Electricity and Energy (MOEE) and Ministry of Petroleum (MOP). Securing energy resources, production and efficient used of appliances to meet the national need both on the short and long term along with the environmental impact are vital element for a sustainable development [48]. Energy efficiency is a strong tool that improve the economic and environmental issues of any country. Such as economic competiveness, energy security, cost saving, local and global environment benefits.

The Egypt government has developed a National Energy Conservation Plan that deals with demand side issues. The energy efficiency measures include pricing scheme as well as technological programs such as efficient appliances. Also there is energy efficiency program for small and medium enterprises which is under credit guarantee company implementation. Egypt government implements 60 MW Ain Sokhna thermal power plant based on super critical boiler in the MENA region, it is the first of its kind because it is energy efficient compared to the existing boilers [49].

The initiatives to improve the use of energy efficient lamps was approved by the Ministry of Electricity and Energy (MOEE) and set to distribute about 11 million compact fluorescent lamps, which was carried out by the distribution companies [50]. Energy efficiency market support in Egypt [51].

a) Conduction and recommendation of 193 and 20 audits implemented has resulted into saving of 285 toe and 800 t of CO_2 respectively.
b) Supporting local manufacturing in production of efficient lighting system. This increases the market of CFLs from 200,000 lamps to more than 3.3 million in 1999 and 2005/2006 respectively.
c) Access of loan to small and medium enterprises, so as to implement energy efficiency projects.
d) Establishment of energy efficiency center around the project sites. A project website was also created in which the database of large consumers can be access for audit.
e) Involvement of some non-governmental organization (NGO) for promoting the energy efficiency program.
f) Completion of building codes for energy efficiency.
g) A developed standard for refrigerators, air conditioners, washing machine, CFLs, and electronic ballast.
h) Establishing of energy efficiency testing laboratory at NREA for refrigerators, washing machines, for air conditioner is under construction.
i) Implementing a numbers of energy efficiency projects

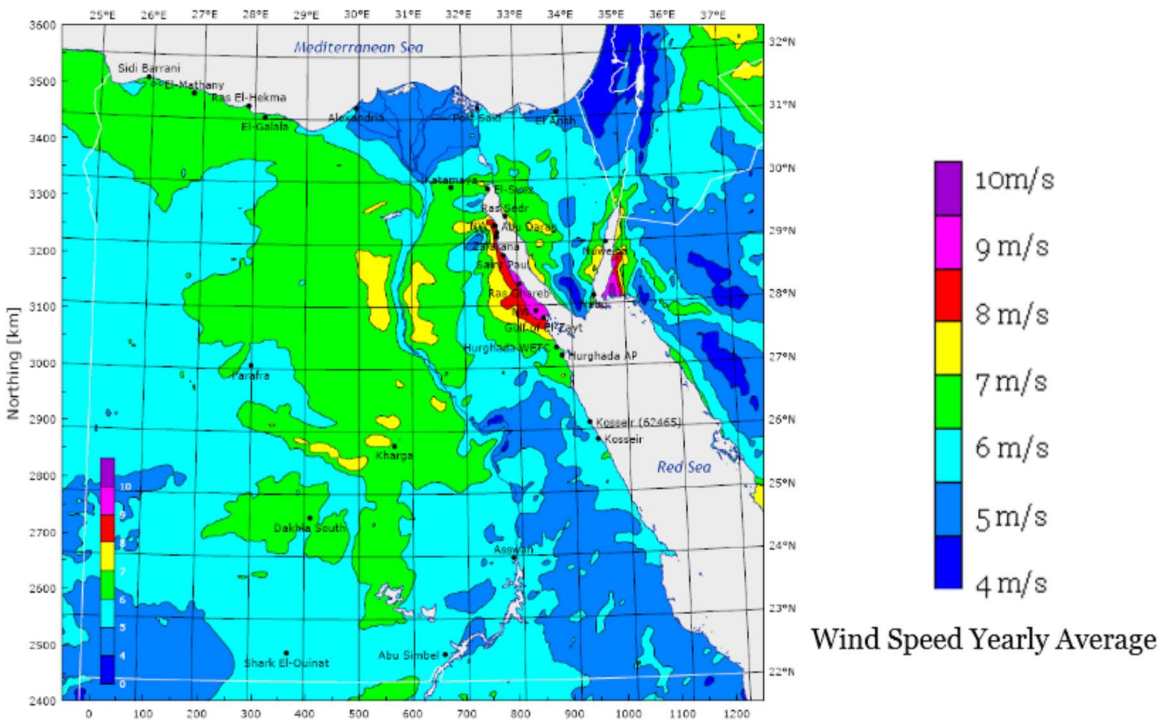

Fig. 7. wind resource map of Egypt [24]. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.).

Table 8
Egypt wind farms based on sites, power and turbine [44].

Site	Power (MW)	Number of turbine
Gulf of El-zeyt	200	100
Zafarana 1	30	50
Zafarana 2	33	55
Zafarana 3	30	46
Zafarana 4	47	71
Zafarana 5	85	100
Zafarana 6	80	94
Zafarana 7	120	141
Zafarana 8	120	141

Fig. 8. Zafarana 5 wind power farm in Egypt [45].

7. Nigeria

Nigeria is located in West Africa, bordered by Niger to the north, Benin to the west, Cameroon to the east, Chad to the northeast and Atlantic Ocean to the south. It lies between latitude 4 $4^{0}16^{i}$ and $13^{0}53^{i}$ to the north of the equator and longitudinal $2^{0}40^{i}$ and $14^{0}24^{i}$ to the east of the Greenwich meridian [52]. It has 923,768 square kilometer land area and over 170 million population [53]. Nigeria is blessed with abundant solar biomass, wind, hydroelectricity and tidal energy sources that can address the problems associated with non-renewable energy source. In November 2005 the Nigerian government approved the country's Renewable Energy Master Plan (REMP) that was drawn by the Energy Commission of Nigeria (ECN) with assistance from the United Nations Development Program (UNDP) [54]. The Master Plan is set to articulate the framework for the development of renewable energy policies, legal instruments, technologies, man power, infrastructures and market to ensure that vision, mission and target is achieved [55]. Table 10 shows Nigeria renewable energy sources and the estimated reserves.

In the process of promoting the potentials of renewable energy sources in Nigeria, the country has set a vision 20–2020 for the use of renewable energy sources to meet the national electricity demand which comprises of energy measures and strategies. Table 11 shows the renewable energy supply projection in MW in Nigeria. Some of the highlighted goals in the draft document are;

a) Achieving a contribution of hydropower to Nigeria's power generation mix of 15% and 20% by the year 2015 and 2020 respectively.

Table 9
Crop residues in Egypt with their production, usage and un-utilized [47].

Crop residues	Production million/tons/year	Present usage	Un-utilized amount million/tons/year
Rice straw	5.0	little amount for animal fodder and composition	3.1
Wheat straw	8.2	Almost all used as animal fodder	0.082
Maize residues	6.7	Almost all used as animal fodder	0.67
Sugar cane residues	4.8	Used as fuel in sugar factories	0.69
Cotton stalks	1.3	Used as fuel in rural area	0.65

Table 10
Nigeria renewable energy sources [56].

Sources	Estimated Reserved
Small hydropower	3500 MW
Large hydropower	11,250 MW
Solar radiation	3.5–7.0 kW h/m^2/day
wind	2–4 m/s at 10 m height
Biomass	
Fuel wood	11 million hectares of forest and woodland
Animal waste	211 million assorted animals
Energy crops and agric residue	28.2 million hectares of arable land

Table 11
Renewable electricity supply projection in MW (13% GDP growth rate) [57].

S/N	Resources	Now	Short	Medium	Long
1	Hydro (LHP)	1938	4000	9000	11,250
2	Hydro (SHP)	60.18	100	760	3500
3	Solar PV	15	300	4000	30,005
4	Solar Thermal	–	300	2136	18,127
5	Biomass	–	5	30	100
6	Wind	10	23	40	50
7	All renewable energy sources	2025.18	4628	15,966	63,032
8	All energy renewables	8700 installed gen. capacity	47,490	88,698	315,158
9	% of renewable energy sources	2.3%	10%	18%	20%
10	% RE less LHP	0.4%	1.3%	8%	16%

Short – 2015.
Medium – 2020.
Long – 2030.

b) 1% wind energy contribution in the generation mix by 2020
c) 1% solar energy contribution in the generation mix by 2020.
d) Replacing 50% of firewood consumption for cooking with biomass energy technology by 2020.
e) Generation of 1000 MW power capacity using biomass resources.
f) Use of locally made renewable biofuel from secondary biomass to reduce the use of fossil fuel for transport.

7.1. Hydropower

Hydropower in Nigeria ranges from micro-mini-small (< 1 MW) to large (< 100 MW). According to survey conducted before the 1973 oil crises, the total estimated capacity of large hydropower in Nigeria is 14,750 MW. However, only about 1930 MW representing 14% is generated at the three main hydroelectric power plants locate at Shiroro, Kainji and Jebba [58]. Small hydropower plants predates Nigeria's independence. Presently, there are 8 SHPs with capacity of 37 MW located in Kano, Sokoto and plateau and Ogun. The planned total of 270 sites are yet to be developed [59]. According to ECN report for the year 2001, Nigeria uses only about 21.5% or 6989 GW/yr of her potential despite the dire need in rural areas and the danger of fossil fuel pollution [60]. Nigeria has been positioned as the 9th African country with technical and economic feasibility of hydro power energy at 32,450 GW h/yr and 29,800 GW h respectively. According to ECN, it uses about 21.5% (6986 GWh/yr) of her potential for the year 2001 [54].

The 3050 MW capacity Mambila hydroelectric power plant is located at the Mambila Mountain in Taraba State of Nigeria. The project which took off in 1982, has suffered decade of neglect but has resumed with a target completion date of 2018. Fig. 10 shows the Mambila hydropower plant site under construction [61,62].

7.2. Solar

Solar is the backbone of all other renewable energy resources such as biomass, wind, hydroelectric and wave [60]. Nigeria which lies in the region that has a great amount of solar energy potential [64], has an average daily solar radiation ranging from 14.4 MJ m^{-2} day^{-1} in the southern part to 21.6 MJ m^{-2} day^{-1} in the northern part [65]. If the country's average sunshine of 6 h a day, is tapped over 1% of land area for the PV power plant, will be capable of generating 1850,000 GW h of energy per year constituting over one hundred times the current amount of electricity it generates [66]. There are two energy sources tapped from solar- thermal and photovoltaic, as well as being non-polluting resources and environmental friendly. Solar thermal has a wide application which solar cooking, solar water heating, for industries solar incubators, solar crop drying, hospitals and household etc. A PV modules have a 25-year lifespan, requires very little maintenance and is simple to operate, making it ideal for use in rural areas for pumping water, refrigeration of vaccines, basic lighting [67]. A French oil company launched one of the biggest PV projects in Nigeria's northern region to generate 1000 MW of solar power. The region is the most suitable location for the project not only because it receives very high level of solar energy but also because it has a very large percentage of scattered population that is ideal for provision of solar power [68]. Fig. 11 shows the yearly average of daily sums of global horizontal irradiation in Nigeria

7.3. Wind

Wind is one of the fastest developing alternative energy technologies in the world. It costs very little to maintain, environment friendly and is the cheapest resource per unit of generated electricity. Wind energy is hugely abundant in Nigeria but is mainly used for irrigation and domestic water supply in rural areas [70]. According to studies conducted by Energy Commission of Nigeria (ECN), total exploitable energy reserve at 10 m height may range from 8 MW h/yr in Yola in the North-East to 51 N W h/yr on the Jos plateau in central region and up to 97 MW h/yr in Sokoto near the Sahel region in the North-West and as low as – 3 m/s in the southern region expect the off shore and coastal region [60]. Currently the percentage of wind energy consumption in Nigeria is very low with no connection to the national grid [66]. Report compiled by Lahmeyer international reveals that, wind energy estimation for the speed of the wind at 10 (ten) selected sites across the country is from 3.6 m/s to 5.04 m/s [70]. The first wind farm project in Nigeria is the 10 MW farm located at Rimi village 25 km south of the state capital, Katsina. The average annual mean monthly wind speed for Katsina state has been computed to be 6.044 m/s. The wind farm comprises 37 wind turbines of 55 m height with 275 kW rated power. At 98% completion as at May 2015, the project is fully supported by the Federal Ministry of Power and Steel and envisioned by the Katsina State government. The average annual mean monthly wind speed for Katsina state has been computed to be 6.044 m/s [71,72] and the 10 MW wind farm site at Rimi, Katsina State as depicted in Fig. 12 .

7.4. Biomass

Biomass are positioned third largest energy sources in the world after coal and oil. Biomass energy is defined as the energy obtained from biological plants and animals matter that can be used to generate electricity. Biomass consist of four main classes which are; agricultural sources, forest and their derivatives, municipal solid waste and animal dung [74]. Nigeria is blessed with abundant biomass sources, the most notable of which is fuel wood, which provides 80 million cubic meters (43.4 × 10^9 kg) annually for cooking and other domestic purposes [75]. The 6.0 × 10^9 MJ content of wood energy would make much higher contribution to Nigeria's fuel wood energy profile but for the fact that more than 350,000 ha of forest and natural vegetation are lost to bush

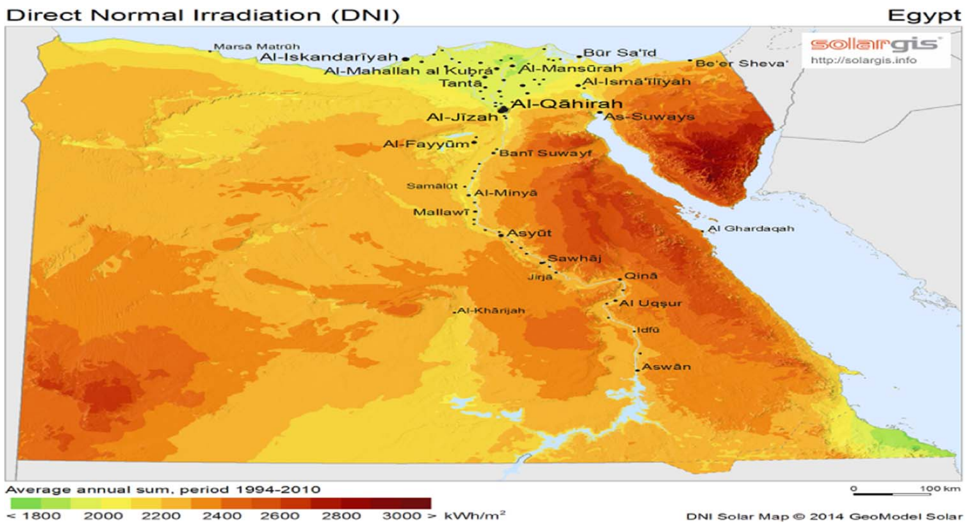

Fig. 9. Solar map atlas of solar irradiance in Egypt [36].

Fig. 10. Mambila hydro power plant sites under construction [63].

fires, land clearing and other factors annually, adversely affecting the 904,100 ha forest land or 9.9% of the country's total land area. About 200 million tons of dry biomass can be obtained from forage grasses and shrubs realizing 2.28×10^6 MJ of energy content. Biomass is one of the key alternative energy resource whose sustainability needs to be carefully understood [60]. According to 1985 estimate, Nigeria generates 6.1 million tons of crop residues and waste with energy content of 5.3×10^{11} MJ as well as 227,500 t of animal and poultry waste with 2.2×10^9 MJ energy content when converted to biogas at 2.93×10^9 kW h with 5.36×10^9 m^3 order. Currently Nigeria is considering to introduce biomass utilization in the transport sector. On the whole, the estimated biomass contribution to the country's energy potential is totally insignificant and not available [75].

7.5. Energy efficiency in Nigeria

Like other developing countries, Nigeria was not left out for the campaign and programs of energy efficiency savings, despite the fact that the major focus on energy sector is on improving electricity generation. The main functions of energy efficiency are; mitigation of environmental effects, reducing the emission of greenhouse gases and saving the cost of energy consumption which is proportional to the energy saving. This will also give the policy maker greater latitude for reducing electricity subsidies. However, two stages upon which the potential of energy efficiency can be exploited. Firstly, how energy is being generated, transmitted and distributed and secondly how energy is consumed in various sectors such as residential, commercial and industrial.

In the process of Nigerian government promoting the use of energy efficient equipment's. The energy commission of Nigeria ECN in partnership with the Cuban government and with the support from ECOWAS has been distributing of million compact fluorescent lamp (CFL) free to replace the incandescent lamps. National Center of Energy Efficiency and Conservation (NCEEC) in partnership with University of Lagos are researching and developing in energy efficiency and conservation as such promote the use of energy efficient appliances and lighting lamps. The project titled “promote energy efficiency in Nigerians residential and public sectors” 2011–2015 which is managed by UNDP and implemented by an energy efficiency unit in ECN aims to introduce energy efficiency policies and measures including standards and labels for refrigerators and lighting lamps in Nigeria.

To promote energy efficiency, a proposed policy measures have been drafted by National renewable energy and energy efficiency policy (NREEEP) which are;

a) Campaign and training of the public on the importance of energy saving equipment's.
b) Enforcement of incentives for consumers that adopts energy saving technologies.
c) Giving incentives for retailers and importers of energy efficient products and promotion of local productions.
d) Active replacements of inefficiency equipment's in governments and public places.
e) Integrating measures for energy efficiency and saving in electricity tariff.
f) Development of energy efficiency building codes.
g) Conduction of research and development activities on energy efficiency and conservation.
h) Improving on public awareness on the benefits of an improved energy efficiency equipment.

The policy has set a target which are;

a) Drafting on all the key components of energy efficiency by 2020.
b) Enactment of all relevant legislation required for policy implementation by 2020.
c) Attain replacement of 40% of old inefficient equipment with the efficient ones by 2020.
d) Sustain best energy efficiency practices beyond 2030 [76].

Table 12
Renewable energy used and REmap options for 2013 and 2030 respectively [80].

	2013 (in PJ/yr.)	2030 (in PJ/yr.)	2030 (in physical units)
Industry sector			
Firewood for boiler	721	608	220,000 average systems
Solar thermal	3	244	90 million m^2 area
Heat for own use in sugar factories i.e. Bagasse CHP	43	104	4 600 $MWth_{th}$
Heat for own use in dairy factories i.e. Biogas digester	1	4	1100 average systems
Industry residue based power	18	63	17 TWh
Renewable energy sources for power generation (grid connected/standalone systems)	155	1557	430 TWh
Percentage of renewable energy sources	29%	30%	
Building sector			
Firewood used in traditional cooking stove	10,270	3115	50 million stoves
Firewood used in efficient cooking stove	571	3 851	180 million stoves
Charcoal used in traditional cooking stove	846	330	5 million stoves
Charcoal used in efficient cooking stove	47	408	19 million stoves
Ethanol used in cooking stove	13	82	2 million stoves
Solar water heating	7	326	120 million m^2 area
Renewable energy sources for power generation (grid connected/standalone systems)	199	1 701	470 TW h
Percentage of renewable energy sources	80%	54%	
Transport sector			
Biodiesel	0	93	2800 million liters
Ethanol	0	123	5800 million liters
Power generation in TW h			
Hydropower	97	402	101 GW
Solar PV	0	70	31 GW
CSP	1	160	38 GW
Wind	2	304	101 GW
Geothermal	2	21	3 GW
Distributed solar PV	0	46	24 GW
Biomass	5	37	8 GW
Biomass industrial residues for own production	5	17	4 GW
Percentage of renewable energy sources except hydropower	2%	30%	
Percentage of all renewable energy sources	17%	49%	
Total final energy consumption			
Percentage of renewable energy sources	56%	32%	

8. Renewable energy roadmap for Africa

Africa is involved in the key energy viewpoints from the US Department of Energy's Energy Information Agency (EIA), British Petroleum (BP), International Energy Agency (IEA) and International Renewable Energy Agency (IRENA). Every data set has different stages of descriptive information, reporting, and aggregation. According to International Renewable Energy Agency (IRENA), African continent can generate almost a quarter of its energy demand by the use of clean indigenous renewable energy by 2030. The 2030 all-inclusive roadmap for Africa's energy transition established that a mixture of modern renewables can convincingly meet 22% energy demand of Africa by the end of 2030. According to the report also, scaling up up-to-date renewables in Africa is an affordable means to support fast rising energy needs while increasing energy access, improving health and attaining sustainable goals. To accelerate Africa's uptake, 14 actions were recommended by the report. These are regulatory framework to catalyze investment, adopting enabling policy measures to attract stakeholders and promoting stand-alone renewable solution to improve energy access and reduce poverty. Table 12 shows the amount of renewable energy used and REmap options for 2013 and 2030 respectively. Where PJ, TWh and $MWth_{th}$ are pet joule, terawatt-hour and megawatt-thermal [77–80].

9. Energy policy in Africa

While practically, all the energy policies for each countries in African continent cannot be presented here, an extensive policy and plan reviews of both national and regional have been undertaken for this paper. A lot of countries such as South Africa, Ghana, Angola, Cameroon, Kenya, Ethiopia and Rwanda have national energy policies, but the time limit varies (on the average of 5–20 years), as to the extend in which they are frequently updated and implemented systematically. South Africa, Ethiopia and Ghana relatively have a cohesive set of energy policy brochures. Majority of the countries in Africa started to inaugurate policies with the aim of increasing renewable energy into the energy mix. In some cases, energy policy is part of broader policies design to reduce poverty and boost economic growth, such as Rwanda. Some countries focused on some particular sectors as presented in Table 13 below.

For instance, Nigeria (gas and renewable energy master plan), Tanzania (power system master plan) and Mozambique (natural gas master plan). Most of the African countries have targets for electricity access and policies in place, but no similar provision for clean cooking [7,81].

10. Needs for grid extension

The early days of electrical energy generation, distribution were direct current (DC) based. Hence, the supply voltage was limited as well as the distance covered between generation and the consumers. They used local storage such as batteries to mitigate the shortage in terms of less solar irradiant and wind intensity especially at the night which are directly coupled with the DC grid. Advancements of technology led to the coming of a transformer with the emergence of Alternating Current (AC) grids, allowing for electrical energy to be transported over longer distance. The balancing and storage needs are the very important issues in case of intermittent renewable energy sources, since they are not consistent [82].

Intermittent renewable energy sources in Africa were not fully explored. They are used as off grid system in local remote areas which are mainly used for irrigation purpose, water pumping, powering traffic and street light, vaccine refrigeration, small scale industries, crops processing, and powering rural clinic etc.

Table 13
Selected energy policies and targets of few Sub-Saharan African countries [81].

Country	Sector	Policies and targets
Angola	Power	New power market model implementation with single power purchaser and equal right for both the public and private power utilities.
	Access	Electrification rate increase from 30% to 60% by 2025.
	Integration	Link transmission lines with Namibia and Congo.
DR Congo	Access	Electrification rate increase from 9% to 14% by 2015 and 26% by 2020.
	Power	Declaration of stricter standards for electric motors.
Ethiopia	Renewables	New renewables energy capacity targets for geothermal, hydro and wind.
	Access	Distribute 9 million improved cooing stoves by 2015.
Ghana	Oil and gas	Strategy to increase exploration, reduce poverty by utilizing the revenues, maximize local participation and develop a petrochemical industry.
	Efficiency	The transmission lines losses reduce to 18% by 2018 as well as the lighting and air conditioners are well labels and standardized.
	Renewables	Established feed-in tariff by the Renewable Energy Act in 2011.
Kenya	Efficiency	Set a standards for electrical appliances, energy efficiency obligations for utilities and enforcement of energy efficiency standards – energy bill 2014 provides for the creation of an Energy Efficiency and Conservation Agency.
	Buildings	Kerosene used as household fuel to be eliminated by 2022 and requirement to install solar water heaters in buildings served by the grid.
Mozambique	Gas	Master plan approved in 2014 for maximizing the value of gas resources.
	Access	Electrification rate increase from 39% to 85% by 2035.
	Renewables	Install of 50 000, 5 000, 2 000 of lighting systems, refrigeration systems and televisions respectively powered by solar PV or wind turbine systems in off-grid areas and 100 00 solar water heaters by 2025.
Nigeria	Oil and gas	Draft Petroleum Industry Bill tend to revise various areas of the existing framework.
	Power	As set up in the Roadmap for power sector reform that continue sector-wide reforms to allow private investment as such establish a competitive electricity market and achieve reliable power supply.
	Access	Provide reliable electricity available to 75%, 100% of the population by 2020 and 2030 respectively- connect an average of 1.5 million households per year.
	Buildings	Announced the design and implementation of minimum energy performance standards for appliances and industrial equipment.
Rwanda	General	Expand the transmission systems network by 2 100 km by 2017 and reduce share of bioenergy in primary energy demand to 50% by 2020.
	Access	Electrification rate increase from 17% to at least 60% by 2020 and give access to all schools and hospitals by 2017.
Senegal	Renewables	20% target of total energy supply from renewable energy sources by 2017.
South Africa	Renewables	The update of 2013 Integrated Resource Plan sets out a strategy to diversify the power mix, moving strongly towards low-carbon sources of power supply.
	Energy prices	Electricity prices to be adjusted gradually to better reflect costs and Carbon dioxide CO2 tax under consideration.
Egypt	Renewables	Implement new laws to attract foreign investors in the renewable energy sector so as to enable Egypt to meet its target of 20% renewable energy production by 2020.

Grid extension is a viable to cater for excess electricity generated by non-hydro renewable energy sources. In developed and developing countries, they have introduced feed-in-tariff and net metering programs, so as to encourage the use of renewable energy sources. This programs tackle the issue of excess electricity by the non-hydro renewable energy sources. Feed in tariff and net metering known as net energy metering are both methods design to speed renewable technologies investment, (e.g. solar panel and wind turbine) by allowing energy producers (e.g. homeowners) to be compensated for the energy feed back into the utility grid. There are basically three types of renewable electrical energy configuration in used today, these are; standalone off-grid system, battery-based grid tie system and batteryless grid tie systems.

1. Standalone system: this is a configuration in which there is no connection between the system and the grid. It uses battery as a backup in the case of low input or high energy demand.
2. Battery-based grid-tie systems: this type of configuration is connected to the grid so that whenever there is excess electricity from the renewable system, it inject to the grid and vice-versa.
3. Batteryless grid-tie systems: this is the most simple among the configuration. It has no battery but it is connected to the grid utility. The system can be made up of solar modules, wind turbine, hydro turbine or a combination of both with an inverter [83].

11. Energy storage systems

The process of converting electrical energy into another form of energy and later accessed when it is needed is termed energy storage. The application power, energy rating, response time, operating temperature etc. determines the type of energy storage system suitable for a particular application. The characteristics of various energy storage technologies is illustrated in Table 14.

Currently, the state of energy storage (ES) is mainly categorized by the following; the developing technology under demonstration, integration of system with improved power electronics and the absence of recognized planning tool that will help in understanding the storage system and differences on the design of the storage system [84,85]. Sections 11.1–11.5. discussed the different types of storage system technologies in detailed [84–90].

Energy storage system is mainly classified into the following; thermal, chemical, mechanical and electrical storage systems. Thermal storage systems are classified into low temperature ES and high temperature ES. Chemical energy storage system comprises of chemical ES (batteries), Electrochemical ES (fuel cells) as well as Thermochemical ES (solar hydrogen, solar metal, solar ammonia and solar methane). Mechanical energy storage consist of potential ES (compressed air and pumped hydro) and kinetic ES (flywheels). Lastly, Electrical energy storage which includes; electrostatic ES (capacitors and supercapacitors), and Magnetic/current ES (superconducting and magnetic) [91].

Table 14
Energy storage systems [85].

Type	Energy efficiency (%)	Energy density (W h/kg)	Power density (W/kg)	Cycle life (cycles)	Self-discharge
Pb-Acid	Between 70 and 80	Between 20 and 35	25	200–2000	Low
Ni-Cd	Between 60 and 90	Between 40 and 60	140–180	500–2000	Low
Ni-MH	Between 50 and 80	Between 60 and 80	Up to 220	< 3000	High
Li-Ion	Between 70 and 85	Between 100 and 200	Up to 360	500–2000	Average
Li-polymer	Up to 70	Up to 200	Between 250 and 1000	> 1200	Average
NaS	Up to 70	Up to 120	Up to 120	2000	Nil
VRB	Up to 80	25	Between 80 and 150	> 16000	Negligible
EDLC	Up to 95	< 50	Up to 4000	> 50000	Very high
Pumped hydro	Between 65 and 80	0.3	Nil	> 20 years	Negligible
CAES	Between 40 and 50	Between 10 and 30	Nil	> 20 years	Nil
Flywheel (steel)	Up to 95	Between 5 and 30	Up to 1000	20,000	Very high
Flywheel (composite)	Up to 95	> 50	Up to 5000	20,000	Very high

11.1. Pumped hydro storage

In pumped hydro storage technology, the working principle is such that water pumped from one reservoir to another at a higher height, often during off-peak and other low electricity demand periods. This technology is perhaps the first and biggest of all the commercially accessible energy storage technology. Facilities of pumped hydro exist in size of up to 1000 MW range, there are also found small sizes of less than a megawatt and even a few kilowatt usually in isolated grid. Pumped hydro storage known to have the characteristics of reasonable high efficiency of 65–80%, power capacity of normally 100–1000 MW, its capacity to store large and a long life span of 30–60 years, has made it to become very popular.

11.2. Compressed air energy system

Compressed air energy storage (CAES) is a technology in which energy is stored as compressed air for future use. A standard gas turbine is used to extract the energy, turbine phase used for compressing air is replaced by CAES thereby avoiding air compression by the use of natural gas. The exothermic and endothermic nature of the air compression and expansion has made the system to be complex. A typical compressed air energy storage system uses an existing underground site such as rock cavern, a salt dome or an abondone which is then released during peak day-time hours to power a turbine for power generation.

CAESs have been painstaking for many applications, more particularly for electric grid support for load leveling applications. In such schemes, energy is kept during periods of low demand and then converted back to electricity when the electricity demand is goes high. Commercial systems use ordinary hollows as air reservoirs for the purpose of storing large amounts of energy; installed commercial system capacity ranges from 35 to 300 MW.

11.3. Battery energy storage system

Battery energy storage (BES) is basically classified under electrochemical energy systems. It consist of two electrodes separated by an electrolyte. Ions from the anode are released into the solution and deposit oxides on the cathode during discharge process. The fast growth witnessed in power electronics devices has led to the massive development in the design of battery storage systems.

Battery storage system (BSS) is designed in such a way that the chemical energy stored in it, is converted into electrical energy and vice versa during charging process. BSS components consist of batteries, control system, power conditioning system (C-PCS) and protection system. Batteries are used for both high and low voltage applications depending on the power usage requirement. The most extensive storage devices used for power system application is the battery. Deep cycle battery with an efficiency of 70–80% is the most common battery used in power system application. Mostly, batteries are classified in to low temperature internal storage and high temperature external storage systems as presented in Table 14. The low temperature types usually works at room temperature. Electrochemical system can be design based on internal or external storing operation and their major difference is allowing for separation of energy conversion units from active constituents. This arrangement allows for design and sizing of power and storage section. Lead acid (PbO2), nickel cadmium (NiCd), lithium ion and nickel metal hydride (NiMH) are the typical examples of low temperature battery having internal storage system.

Table 15
Battery Energy Storage System (BESS) applications in power system [86].

S/N	System/location of BESS	Suggested application and study carried out
1	Near consumers	Recommended for limiting daily peak demand so as to-improve security (endure disturbances through peak loads), reduce the need for spinning reserve, reduce the need for demand forecasting and peaking generators
2	Israeli isolated system	Simulation studies to study the effect of a 30 MW BESS on frequency regulation of the system.
3	Wind-Diesel stand-alone system	Monitoring active and reactive power of redox flow batteries by neural networks. Simulation studies carried out to observe the effect of load and wind instabilities
4	Fixed speed wind farm	Levelling wind farm power output, improving temporary stability and providing reactive power backing are illustrated through simulations
5	Interconnected power system	Remove doubt in predicting the annual peak demand. Further applications include; load smoothing, backup supply, damping of inter area oscillations are established experimentally (lab setup) using 100 Ah, 110 V lead-acid batteries
6	Interconnected system	Peak load shearing, compensate load destabilize, harmonic and reactive powers (maintain nearly UPF and operate as UPS. A 5-kVA prototype BESS used to show these in a laboratory
7	Demand side applications	Can be function in grid link (active filter, power conditioner, voltage stabilizer) or stand-alone (UPS) mode. Demonstrates these features experimentally (lab) on a 5-kVA battery and through simulation
8	Laboratory Set up	Load leveling, active filtering and operation as UPS-these features of the considered BESS controls are demonstrated experimentally on a 100-Ah, 110-V lead-acid battery bank

Sodium sulfur (NaS), sodium nickel chloride (NaNiCl) and flow batteries are the examples of high temperature type of the external storage facilities. Table 15 shows the direct Battery Energy Storage System (BESS) application in power system.

11.4. Superconducting magnetic energy storage system

Another emerging storage system device is the superconductive magnetic energy storage (SMES). In this technology, the dc current flowing through a superconducting coil produces a magnetic field where the energy is stored. They have a high operational cost as a result of their construction and as such, they are best suited to supply constant, deep discharges and continuous activity. A solenoid or a collection of two or more solenoids are usually used for the construction so that it will cancel the magnetic field about them. SMES has the advantage of possessing of above 90% and one of the highest in term of power densities of any storage system. High dynamic response in the range of millisecond is also an additional benefit of SMEA. The fast response period (below 100 ms) of these systems marks them ideal for regulating network stability (load flattening). These facilities currently are in the range in size of up to 3 MW units and are usually used to provide grid stability in a supply system and power quality at industrial facilities demanding ultra-clean power such a chip construction facility.

11.5. Flywheel energy storage system

Flywheel energy storage system (FESS) stores energy by means of accelerating a rotor up to a high speed and keeping the energy in the system as inertial energy. This theory has been functioned in synchronous generators to give out a stable voltage. This technology has become smart for a number of application as a result of the recent advancement in electronics aspect of power and engineering materials. Flywheel systems is characterized by its ability to provide very high peak power. FESSs has virtually infinite number of charge–discharge cycles as well as high power and energy density. Therefore, they are used in the area of transport system and power quality. The flywheel energy is released by reversing the process and using the motor as generator. As the flywheel releases its stored energy, the rotor slows down until it is fully discharged. Although most of the flywheel technology was established in the auto and space industry, flywheels have witness maximum commercial achievement targeted for power distribution abilities ranging from 150 kW to 1 MW. The speed of rotation of flywheel determines its application. The FESS can be categorized as low- and high-speed FESSs with respect to the speed. The electrical machine and bearing is a function of the flywheel speed of rotation. The systems with more speed are more complicated as a result of technological requirements. These systems are compressed and have low maintenance costs and requirements compared with battery storage systems. The key focus for development of this technology is for the purpose of power quality and reliability market.

12. Seasonal variation

Seasonal variation of solar irradiant and wind intensity are very important in siting a solar energy and wind energy plant. Solar PV has a great electrical energy potential with a peak in summer period, although along the equator there is almost constant exploitable potential throughout the year. Electrical energy production using solar PV varies on a diurnal bases from dawn to dusk peaking during midday and lastly short term fluctuation of weather condition such as clouds and rainfall, impact on the inter-hourly amount of electrical energy that can be harvested. Wind power can fluctuate at various time scales - it is subject to seasonal variations of peak electrical energy production in winter or summer period depending on the region, as well as diurnal and hourly changes. The degree of wind speed variation also depend on the site of the wind farm and the wind speed is much more constant in sea breezes than in land breezes [92].

13. Discussion

Africa is the second largest continent and also the second most populous continent with 54 countries in the world, it has abundant renewable energy as well as fossil fuel for electricity generation which greatly contributes to global warming, cancer and various respiratory diseases, oil crises in the world market, oil crises in the world market. It is therefore, necessary to supplement the fossil fuels with the renewable energy sources.

The Alliance for Rural Electrification (ARE) elaboration of IEA data (ARE 2011) shows that people living without access to electricity have reached 589million as in 2008 and mostly rural areas. As shown by the three case studies of this paper, the potentials of each country are not fully exploited, mainly due to limited policy interest, investment level and poor infrastructural support to harness the renewable energy. In South Africa and Egypt the contribution of renewable energy is significant. As South Africa and Egypt target 42% and 22% of the renewable energy contribution in electricity generation by the year 2020 and 2030 respectively. Nigerian contribution is insignificant due to above factors mentioned earlier. Renewable energy can be generated in small amount as a standalone system. Most of the areas without access to electricity in the African continent are rural dwellers. However, electricity generated from renewable energy sources is the solution because most of the areas are offshore. The cost of transporting electricity to an offshore area is very expensive due to High Voltage Direct Current (HVDC) facilities and equipment's. In order to sustain African economy, energy is the first priority to consider as it is a catalyst of growth and development of any nation.

In summary, the following are the current obstacles to renewable energy developments in African countries: (i) Insufficient policy and lack of implementation of the existing policy. (ii) Insufficient funding of governmental agencies that are responsible for generation, transmission and distribution of electricity. (iii) Mismanagement of funds allocated to the energy sector. (vi) Lack of understanding on the effect of gases emission by the burning of fossil fuels. (v) Lack of awareness of latest renewable energy technologies. (vi) Insufficient collaboration with international bodies on promoting renewable energy. (vii) Insufficient financial resources and expertise knowledge with regard to the implementation of modern renewable energy that would be efficient and cost effective. (viii) Interest of governments and investors to develop a large scale instead of small scale renewable energy production. (ix) Lack of enforceable regulation due to lack of rule of law, corruption and poor governance. (x) Poor market for renewable energy products in Africa as some parts of African continent lack the right policies to develop an efficient market for renewable energy technologies [93]. (xi) Institutional and regulatory barriers such as building a power plant that require a number of legal and regulatory prerequisites for their improvement. Having many agencies makes it take a long time before they approve and issue licenses.

To remedy the above obstacles it requires: (i) Standardization of institutional and regulatory departments and authorities to a single agency that may regulate all the institutional and regulatory bodies. This will dependently reduce the delay for approval and issuance of license. (ii) Public enlightenment and awareness about the importance of building renewable energy resources as they are clean energy sources [94]. (iii) Deregulation of energy sector can promote the use of small scale renewable energy production that will increase the availability of electricity, reduce cost of energy and provide favorable environment for private investors. (iv) The consistence of government policy in addressing the issues about renewable energy sources. (v) External assistance from countries and financial entities to assist in reducing risk in renewable energy deployment by the use of technological equipment and facilities. (vi) Rural electrification programs most integrate renewable energy in

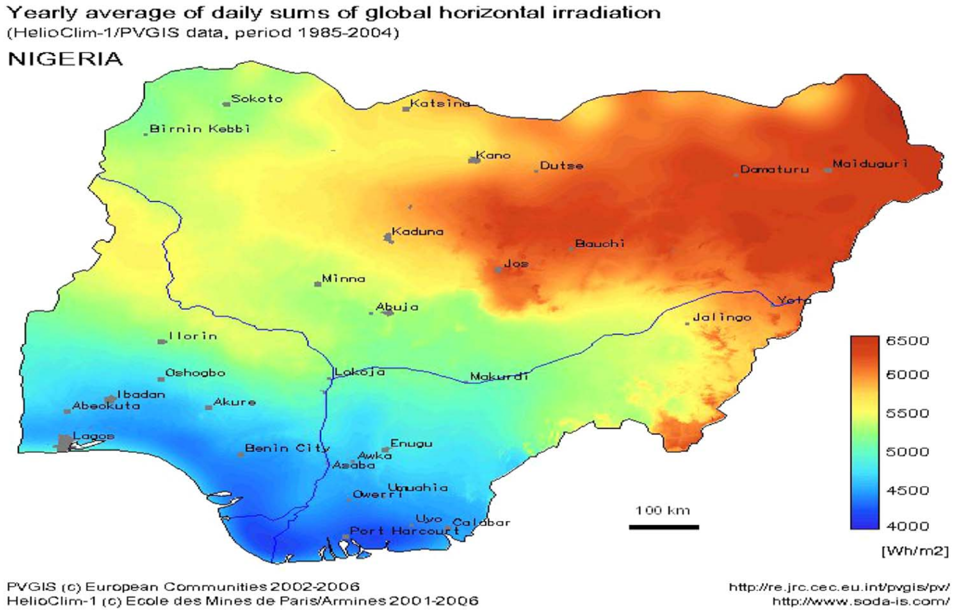

Fig. 11. Horizontal solar irradiance of Nigeria [69].

Fig. 12. 10 MW wind farm site at Rimi, Katsina State [73].

their policy, planning and management which can encourage private investor to function in such areas; Feed-in-tariff should be encouraged by the government of all the African countries, so as to encourage the use of renewable energy sources and to reduce the shortage of electricity. In Egypt and South Africa where feed in tariff had been implemented [95]. Some African government are trying in promoting renewable energy production, in the face of many obstacles for example Egypt and South Africa where the respective governments implemented Feed-in-tariff as a government incentives in promoting renewable energy generation. In Nigeria REMP was set up a 2005 aimed to articulate a natural vision, target and road map for addressing key development challenges facing the country through accelerated development and exploitation of renewable energy. Renewable energy sources are clean and environmentally friendly, that is why developed and developing countries are trying to run away from the use of fossil fuel sources so as to tackle the issues of climatic change. Feed-in-tariff and net metering are very essential programs that promote the use of renewable energy sources. Feed-in-tariff involve connecting your renewable energy sources (e.g. solar PV, wind farm, micro hydro plant etc.) to the utility grid and selling electrical energy to the utility grid so as to get paid at specified amount of money per kWh for a definite contract period of time. Net metering involves connecting your system to the utility grid, but you use the power and it offsets your electrical energy bill. If you don't produce as much electrical energy as you use, then the grid supplies the difference and you get billed for the difference, if you produce more then you use the required demand and the excess just goes to the utility grid.

14. Conclusion

Africa is endowed with abundant energy sources especially renewable energy, yet it is facing a serious crises as a result of failure to harness renewable energy resources, failure to deploy appropriate technology, failure to support stakeholder agencies in the private sector and overdependence on fossil wood and waste of wood resources with its attendant consequences of desertification. This review study focuses on the three major African countries, South Africa, Nigeria and Egypt. South Africa has the greatest model for approaching its energy challenges. This review study focuses on the three major African countries namely South Africa, Egypt and Nigeria. Of the three, South Africa has the best model for tackling its energy challenge through the use of wind and solar energy. Egypt too is promising with its use of hydropower and emergent solar power base. Nigeria has great potential but very weak hydro, solar and wind power in that order. In the three countries and indeed across the African continent access to renewable energy for off-grid, small scale application is key to successful resolution to energy crisis, sustainable development and fighting climate change. Energy storage technologies are very vital for storing electrical energy and be released when needed. Even though, the selection of an energy storage system for a particular application depends on the response time, application power and energy ratings, volume, weight and operating temperature. Feed-in-tariff and net metering are both methods designed to accelerate investments in renewable energy technology and very essential programs that promote the use of renewable energy technology (Figs. 11 and 12).

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