Review of the Updated Status, Potentials and Renewable Energies Plans in Sudan

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Abstract – *Sudan holds abundant renewable energy sources. Its hydro resources are already being utilized or are under development. Besides the hydro resources, there is further renewable energy potential through solar and wind energy, biomass and biogas, and geothermal energy. Sudan provides an excellent base for solar photovoltaic power development. Its favorable geographic position provides comparatively high global horizontal irradiation of 1900 to 2500 kWh/m2/year. The renewable energy sector is a part of electric sector and faced with some problems that delaying its development, one of these problems is ratification and approval of renewable energy laws and regulations that incorporate policies and mechanisms which are recommended and attractive to the private sectors, the presence of monopoly structures and huge numbers of the issued plans.* for enhancing developing of Sustainable Energy in Sudan is by ratification and approval of renewable energy laws and regulations that incorporate policies and mechanisms which are recommended and attractive to the private sectors.

Key Words: solar energy, Sudan National Solar Energy Road Map, Long Term Plan. Biomass, Wind Energy, Small Hydro Power

1. INTRODUCTION

Sudan began the electricity industry in 1908, the first 100 KW generator was installed by English Electric Company and then raised to 500 kW at Burri Power Plant in Khartoum. Due to the demand growth, in 1925 contract signed with group of British companies for a period of thirty years for the development of electricity. Steam generation was started in 1956 at Burri Power station (30 megawatts) 4 steam turbines. In 1960, the government Established Central Electricity and Water Corporation which began to extend electricity and water services in major cities in the country. Gas turbines generation began in 1968 at Kilo X Power station (15 MW) Fiat gas turbine. In 1982 Water Corporation was separated from Electricity Corporation. So that each can develop separately and render service independently.

The National Electricity Corporation (NEC) Act was passed also in 1982 to assign NEC to look after the National Grid, at the same time the state governments were assigned to take control of the regional power generating plants [1].

It worth to mentioned that Khartoum North Power Station Phase I, comprised of 2 machines each one is 30 MW capacity was built in 1981 as a gift from British Government, the formal starting was in Dec. 1985 honoured HRH Princess Anne[2]. In 2015, the Electricity sector in Sudan acting under the umbrella of the Ministry of Water Resources, Irrigation and Electricity. The Electricity Sector now currently has an installed generation capacity of 3,227 MW of power, has no wind generation capacity and no grid-connected solar capacity. Approximately 35% of Sudan's population has access to electricity, the power consumption per capita was 335 kWh/ year. As part of the current energy policy, it is the aim of the Government of Sudan to:

a. Increase the overall national electrification ratio to at least from 35% now to 80% by 2031;
b. Connect all states of Sudan to the national grid by 2031 - as far as practicable.
c. Utilize a high share of renewable energy sources considering economic and technical limitations [3].

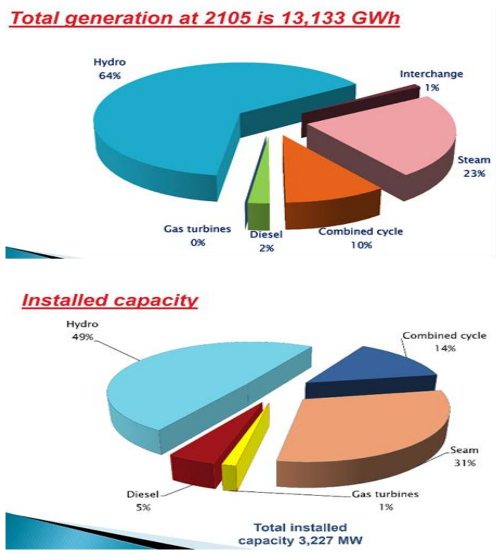

Fig-1: Sudan total generation and installed capacity by type [1]

Sudan is in the midst of an energy transition. After losing its oil-rich South the country is now seeking for alternatives. Alternatives that can secure its energy needs and yet meet

Sudan's action plan in combatting climate change. There are many types of renewable which provide clean environmental-friendly energies. These range from biomass (bioenergy), hydropower, solar, wind energies and more other. Renewable energy is a promising option for electricity generation, especially the wind and PV energy systems as they are clean energy sources and became mature technology. In addition, the wind energy source is considered as the world's fastest growing energy source and the PV energy source is the most easily scalable type of renewable energy generation [4].

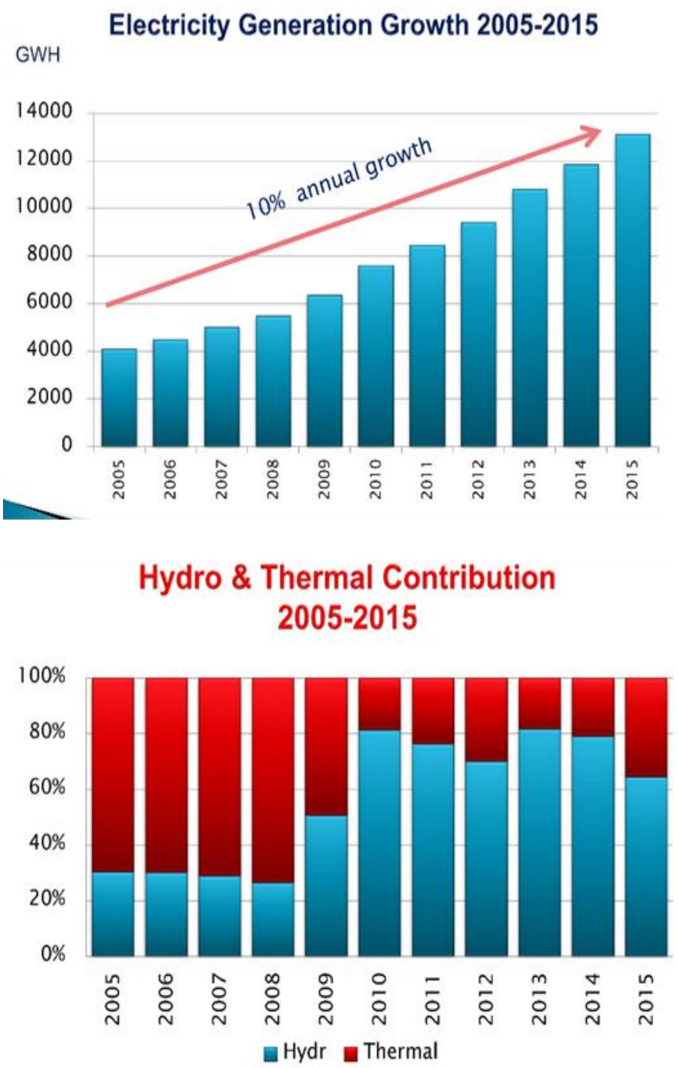

Fig-2: Sudan historical generation growth (2005-2015) [1].

This paper aims to review and updated the status, potential and renewable energies plans in Sudan.

1.1 Renewable Energy characteristic and potential in Sudan

Abundance of the prime natural source in the country (i.e. solar radiation) enhancing solar energy, justifies too the urge of exploring such a technology. Sudan has been considered as one of the best countries for exploiting solar energy since its average sunshine duration ranges from 8.5 to 11 hours a day. It is also worth noting that the technology prime source (i.e. sun light) is free and requires no foreign permission, involvement or sharing. [5].

a- Solar Energy - Photovoltaic (PV) characteristic and potential

Solar photovoltaic (PV) power plants transform, based on a range of semiconductor technologies, solar irradiation into electricity. The direct current produced by the solar power plant modules can run electric appliances or can be fed into the regular power system after being inverted into alternating current. The advantages of PV are the relatively simple and modular technology with low operation and maintenance costs. Its disadvantages are (i) the relatively high investment costs, though they considerably decreased during the past years and a further significant decrease of investment costs is expected in future probably enlarging the potential of PV, and (ii) the intermittent characteristics of the underlying solar resource.

Sudan provides an excellent base for solar photovoltaic power development. Its favorable geographic position provides comparatively high global horizontal irradiation of 1900 to 2500 kWh/m2/year (which is roughly twice the typical value for central Europe) throughout the country.
PV will be applicable for the entire country for on- and off-grid solutions. In order to approach the existing network close to the major load center, PV-arrays can be arranged around Khartoum 220/ 110 kV - network ring allowing easy network access and smooth integration for electric power production. This has the potential to provide power where and when it is needed and to replace fossil fuel based generation. Also PV-array distribution in smaller cities and villages will be the leading renewable approach for fast and smooth electricity production upgrade in rural areas:

It has the potential to either replace more costly fossil fuel based generation or provide power to previously unsupplied areas [6].

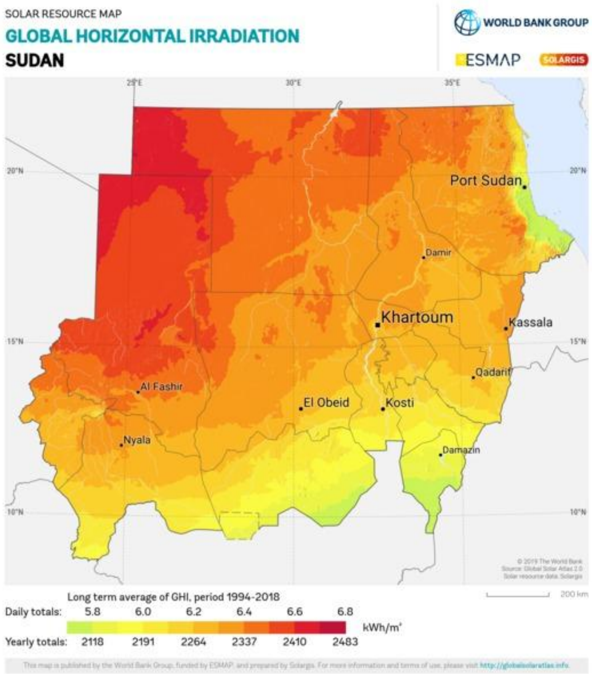

Fig-3. Sudan Global Horizontal Irradiation (GHI) [6].

b- Solar Energy - concentrating Solar Power (CSP) characteristic and potential

Concentrating solar power (CSP) plants transform direct solar irradiance (DNI) into heat, which in turn is transformed into electricity by means of a standard steam turbine and generator.

Hence, the CSP plant can directly feed into the regular power system. The advantages of CSP, in comparison to PV, is its potential to store and regulate the power output. Its disadvantages are the relatively high investment costs (compared to PV and wind) for the rather sophisticated technology which causes also higher operation and maintenance costs. Further CSP needs considerable amounts of water (depending on the cooling technology). It is restricted to areas with high direct solar irradiance (compared to direct and indirect solar irradiance for PV) and is influenced by the intermittent characteristics of the underlying solar resource (depending on the storage capacity and power system needs).

The potential resources is similar to PV the solar resource for CSP, the direct horizontal irradiance (DNI), in Sudan is relatively high due to its favourable geographic position. However, the DNI resource can be assumed to have a very high uncertainty due to the lack of ground measurement data for the verification of the satellite data. Good sites such as "Wadi Halfa" offer good resources required to develop a financial viable project: indicating DNI values significantly above 2,000 kWh/m2/year, water availability and network access [6].

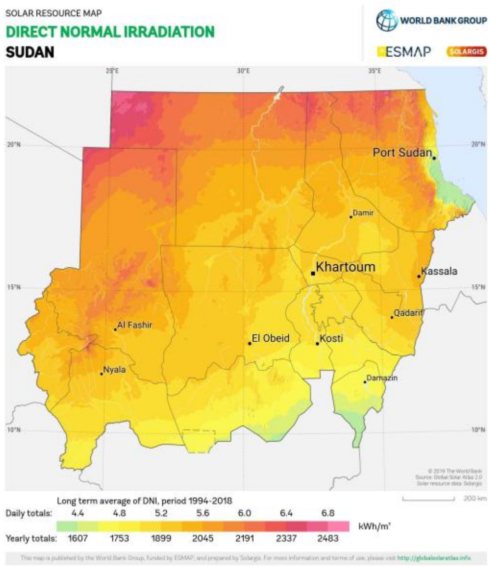

Fig-4. Sudan Direct Normal Irradiation (GHI)[6].

c- Wind Energy characteristic and potential

Wind turbines convert wind energy into electric energy which can be directly fed into the regular power system. The advantages of wind power plants are the relatively low generation costs based on a mature technology. Its disadvantages are the relatively high effort (compared to for instance PV) for operation and maintenance, its restriction to areas with suitable wind energy (potentially far away from load centers) and the intermittent characteristics of the underlying wind resource.

Wind power in Sudan is particularly feasible in strong wind regime areas (e.g. wind speeds of more than 7 m/s), for instance in areas near Dongola and Nyala and in some areas at the Red Sea coast (e.g. Toker). It is expected that additional areas with sufficient potential for wind park planning can be found in the North State along the Nile valley as in [6].

d- Waste to Energy characteristic and potential

Waste to energy (WtE) plants incinerate waste to produce heat and electricity via a steam turbine and generator. While this provides the advantage of firm capacity and energy with high capacity factors (compared to other RES) the investment and thus generation costs can be high.

There is some potential for WtE in Sudan. Specific waste amounts produced in Sudanese cities amount to 150 to 200 kg per inhabitant per year. Waste amounts available in seven cities in the country including Khartoum are deemed sufficient to supply and technically and economically justify the installation of waste to energy WtE plants. Total installed electrical capacities would amount to 68.2 MW including a waste incineration project of 50 MW (electric) in Khartoum. The other six cities suitable for smaller capacities to be installed include Nyala, Port Sudan, Al Obeyed, Kosti and Rabak, Wad Madani and Kassala. A steady and reliable provision of waste in terms of quantities and quality for incineration of the essence to sustain technical and economic feasibility of the plants [6].

e- Biomass and Biogas characteristic and potential

The usage of biomass resources in Sudan for grid connected electricity production have been separated in the two energy conversion paths direct combustion and anaerobic digestion.

Power plants (or combined heat and power (CHP) plants, if the produced heat is also used) based on direct combustion use solid biomass as fuel that is directly burned on a grate to generate electricity via a conversion process with a water-steam-cycle including steam turbine and generator. Power (or CHP) plants based on biogas generate electricity via a conversion process where biogas is produced by anaerobic digestion (fermentation) of biomass that is used as fuel for internal combustion engines with generator. Both technologies provide the advantage of firm capacity and energy with high capacity factors (compared to other RES) – depending partly on agricultural seasons.

Potentially available residues in Sudan for direct combustion are basically lignocellulosic (woody) biomass like bagasse (by product from production of sugar from sugar cane), cotton stalks, cotton waste, and groundnut shells (livestock excrements were considered exclusively for anaerobic digestion) but due to techno-economic constraints only direct combustion of bagasse was taken into consideration for electricity generation. Bagasse is already used as fuel for the combined heat and power (CHP) plants at all sugar factories in Sudan. The sugar factories are owned by Sudanese Sugar Company (SSC) and Kenana Sugar (KSC) and are located in New Halfa, Assalaya, Guneid and Sennar (all SSC) and Kenana (KSC).

The potentially available residues for anaerobic digestion in Sudan are livestock manure, byproducts and waste from dairies, waste water from slaughterhouses as well as sewage (or sewage sludge), and molasses and vinasse of sugar cane, but most residues are limited.

The locations of existing and potential direct combustion and biogas power CHP plants are mainly outside the greater Khartoum area, close to the industrial scale biomass production in the irrigation schemes.

It is recommended to retrofit or replace the existing combined heat and power plants of the five sugar factories by more efficient plants with higher power capacity. Co-combustion of bagasse with other biomass residues should be evaluated. Direct combustion of bagasse is expected to be the largest potential for biomass based power generation in Sudan. The potential could be around additional 50 MW (electric, rough estimate) but the evaluation of the current situation of the existing CHP plants at the five sugar factories in Sudan from SSC and KSC is still in progress as in [6].

f- Geothermal Energy characteristic and potential

For the use of geothermal energy the heat within the Earth's mantle is pumped up to the surface and transformed into electricity by means of a steam turbine and generator. While this provides the advantage of firm capacity and energy with high capacity factors (compared to other RES) the development and thus generation costs can be high.

The analysis of the resource potential in Sudan is still on-going and first results of geothermal potential in Bayuda area are yet available indicating temperatures of approximately 200 degree Celsius. However, further study analysis is required to come up with a reservoir model in order to provide capacity estimations.

The detailed geothermal study part continues for diverse areas in Sudan and results are not finalized. Geothermal resources appear so far not relevant for a strong impact on the overall electricity production for Sudan [6].

g- Small Hydro Power Plants characteristic and potential

advantages are the comparatively low generation costs if installed at existing facilities (e.g. dams, irrigation schemes) since the energy will be a by-product of their main purpose (mainly irrigation). The main disadvantages are the seasonal fluctuation of the energy generation and the limited possibilities to regulate the energy production according to the demand. Resource potential are estimated to be in a range of few 100 kW up to few MW but the overall potential in the country may sum up to 50 - 100 MW [6].

1.2 Sudan Experience in Renewable Energy Technology Application

In Sudan great attention is given to the utilization of the renewable energy potential of the country. This great attention leads Sudan to create in 1991, the Ministry of Higher Education and Scientific Research (MHESR) to take responsibility for all matters relating to non-conventional/renewable energy. It undertakes the role of renewable energy policymaking, planning, promotion, and coordination [7].

There are three distinct groups contribute to research, development and utilization of the resources [8]:

These are:
1. Research institutes
2. Universities, and
3. Private sector

In recent years Energy Research Institute (ERI)-National Centre for Research (NCR)-MHESR has overseen the development of a broad base of technologies including biogas plants, solar thermal and PV systems, wind turbines, small and micro hydropower units, energy from urban and industrial wastes and even improved cooking stoves, Table 1 summarizes the potential and the current status of renewable energy development in Sudan [9].

Table -1: Renewable Energy Achievement in Sudan 2010

Source/system	Status (units as of July 2010)
Industrial solar heaters (16 m^2-80 m^2)	150
Solar cookers	2000
Solar stills (1 m^2-10 m^2)	100
Solar dryers	10
PV solar refrigerators (120 W-250 W)	200
PV communication systems	30
PV solar water pumps (1.5 kW-5.5 kW)	120
PV solar lighting systems (40 W-1.5 kW)	1000
Source/system	**Status (units as of July 2010)**
Wind pumps (diameters 2.4 m-7.4 m)	25
Wind generators (research facilities)	4
Biomass gasifiers	3
Improved stoves	25000
Briquetting plants (600-2000 tonnes per season)	5
Biogas plants	200
Current driven turbines	10

Regarding renewable energy as stated in [7], the Ministry of Water Resources, Irrigation and Electricity has Rural electrification program which aims to provide the electricity to the households in rural areas far from the grid by installing Solar Home Systems (1.1million 50-100-200Wp solar home system (SHS)) from 2013 to 2032 with a budget of ≈600million US $.A pilot project for 100 SHS in four different states was implemented. Large projects (3 Wind Energy generation projects with a total capacity of 300 MW in Dongola, Nyala and Red Sea and 4 Solar Energy generation projects with a total capacity of 20 MW in Albageir, Nyala, Alfashir and Algneina). The ministry has made studies for different renewable energy technologies such as:

- Wind Atlas.
- Solar Atlas.
- Feasibility study for 50 MW waste to energy project.
- Feasibility study for Integrated Solar Combined Cycle (ISCC) at Garri Combined Cycle Power Plant.
- Reconnaissance study of geothermal potential.
- Geo-scientific study for Bayuda desert.
- And feasibility study for rural electrification (micro grids) using biogas from animal and agriculture wastes has been conducted.
- Under the project Promoting the use of electric water pumps for irrigation in Sudan, the Ministry of Water Resources Irrigation and Electricity, supported by the UNDP-GEF grant of USD 4,365,753, adopted a solar irrigation program for replacing diesel water pumps with PV pumps in the Northern State of Sudan. The project is concerned with installing 28 pilot pumps (20 × 3.12 kWp units, 5 × 5.12 kWp units and 3 × 29.6 kWp units) to act as demonstration units, the creation of a financing mechanism with subsidy from GEF funds, and the subsequent financing and installation of 1,468 pumps. The project implementation unit already installed 28 PV pumps in the Northern State [10].
- The 'Promoting Utility Scale Power Generation from Wind Energy' project further establishes frameworks that encourage private investments in the wind energy grid, The Dongola wind farm is planned to be implemented in five phases. The development objective of the project is to help diversify Sudan's power sources and reduce its reliance on fossil fuels, particularly for future expansion and to reduce greenhouse gas (GHG) emissions by promoting the use of wind energy. The project has a total budget of US$ 217,486,364 from which US$ 250,000 is from UNDP, US$3,536,364from the GEF and the remaining from the Government, which will be utilized over a period of five years since January 2015 to build 100 MW wind energy farm in North State, Sudan. The installation of 100 MW capacity in Dongola was not achieved due to many reasons which were a big risk yet out of the control of the project team i.e. beyond the scope of this project's control due to the recently lifted embargo that was imposed on Sudan and the snowball effects from the cessation of South Sudan from Sudan which impacted on Sudan national budget revenue from the formerly oil-rich regions lost when the South gained independence from Sudan. The implementation of the Dongola Pilot Wind Farm finally has been awarded to Emergya, where the the contract authorizes the supply and installation of one 900 kilowatt turbine. Development of the turbine shall begin on March 16 and construction is expected to be finished by January 2021 [11].

2. SUDAN NATIONAL RENEWABLE ENERGY (RES) PLANS

The secession of South Sudan induced multiple economic shocks. The most important and immediate shock was the loss of the oil revenue that accounted for more than half of Sudan's government revenue and 95% of its exports. This has reduced economic growth, and blocked assets of the Sudanese government [12]. Adding to this situation the wars and conflicts, also the country suffered further from U.S. sanctions since 1997, that involved a comprehensive trade embargo and blocked assets of the Sudanese government The country performed extremely poorly on the 2010 World Bank's Worldwide Governance Indicators, scoring well below 10 (on a scale of 0 to 100) in all areas of governance assessed, and to date still showing no signs of improvement [13][7]. In the last 10 years the electrical sector passed through different reforms and shaping, this situation and the lack of financing and investment in the sector lead to fail in developing the renewable energy in Sudan and build a unique master renewable energy plan as a road map to lead the country forwarding in using its abundant non-conventional energy resources. The authorities of electrical sectors produced the flowing plans respectively.

2.1 Long Term Plan- Lahmeyer International (2012-2031)

In 2011, the Ministry of Electricity and Dams (MED) has contracted Lahmeyer International (LI) for the consultancy services for the development of a long term power system planning study to cover the period 2012-2031, within the expansion planning, RES are considered as summarized by the following figures as in [6]:

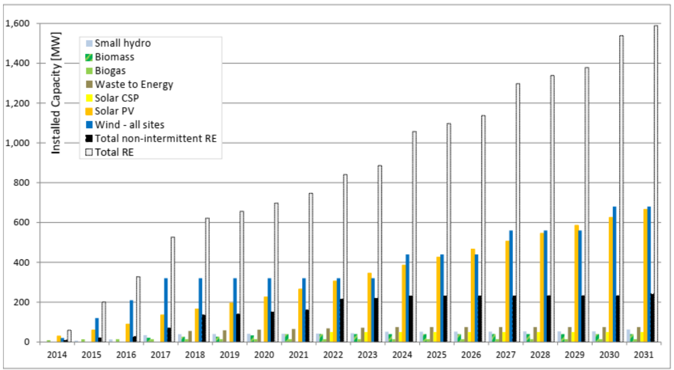

Fig-5. Cumulative installed capacity by RES for 2014–2031

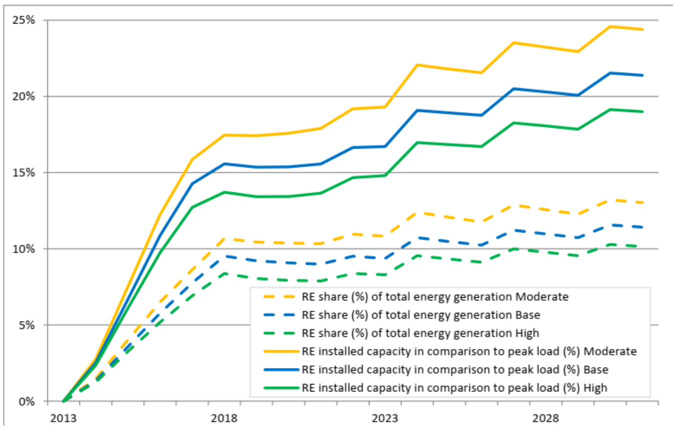

Fig-6. RE share of total energy generation and RE installed capacity in comparison with annual peak load 2013–2031

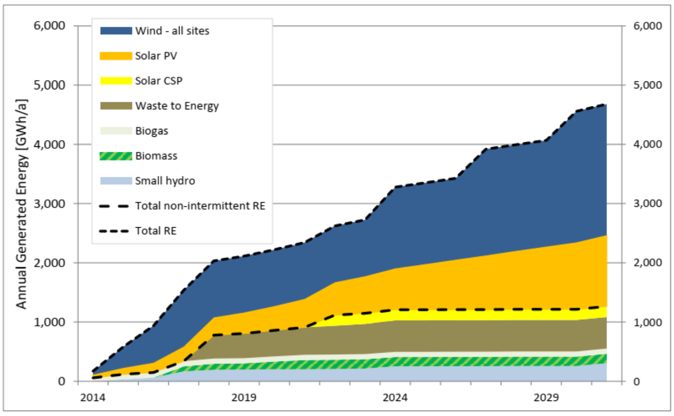

Fig-6. Cumulative annual generated energy by RES for (2014–2031)

2.2 Sudan National Solar Energy Road Map (International Solar Alliance (ISA))

The International Solar Alliance is an alliance of 121 countries initiated by India, most of them being sunshine countries, which lie either completely or partly between the Tropic of Cancer and the Tropic of Capricorn. The International Solar Initiative aims to massively reduce solar energy costs by providing a collective response to the main common obstacles in terms of technology, finance and capacity to the massive deployment of solar energy. The Ministry of Water Resources, Irrigation and Electricity submitted a Renewable Energy Master Plan (REMP) which aims to:

I. To increase the percentage contribution of solar energy to the total energy mix.

II. To extend electricity to rural and remote/ off-grid areas, through the use of solar home systems and promote solar photovoltaic applications to ensure that solar energy can be used for production of electricity.

III. To increase the use of solar water pumps for irrigation and drinking water to achieve stability and economic development.

IV. To preserve the environment and ensure reduction of pollution from the use of fossil fuels.

The National Solar Energy Road Map [14] is summarized in the following Table 2:

Table -2: Summary of Sudan National Solar Energy Road Map

Year	large scale projects (MW)	Mini Grid (MW)	Rooftops (MW)	off Grid Solar Home Systems (MW)	Solar for Irrigation and Drinking (MW)	Number of water pumping units	Total MW per Year	Cost per year in Million US Dollar
2019	200	13	10.8	22.404	225	11500	471.204	696.204
2020	200	29	1.3	37.208	225	11500	492.508	717.508
2021	50	26	1.8	38.409	180	10000	296.209	476.209
2022	50	12	2.3	40.812	180	10000	285.112	465.112
2023	50	6.5	2.8	42.147	180	10000	281.447	461.447
2024	50	8	3.2	42.799	180	10000	283.999	463.999
2025	50	9	3.9	51.61	180	10000	294.51	474.51
2026	0	9.5	4.6	54.68	180	10000	248.78	428.78
2027	50	12	5.3	56.298	180	10000	303.598	483.598
2028	200	11.5	6.2	60.138	180	10000	457.838	637.838
2029	200	13	7.8	61.363	180	10000	462.163	642.163
2030	500	14.25	10	65.635	180	10000	769.885	949.885
2031	100	16.25	12	71.234	180	10000	379.484	559.484
Total of Programme	1700	180	72	644.737	2430	121500	5026.737	7456.737

2.3 Renewable Energy Master Plan -RCREEE

In 2019 the Joint Venture consultancy consortium, which consist from the Regional Centre for the Renewable Energy and Energy Efficiency (RCREEE) and Newtech Consulting Group (Newtech) was appointed by the Wind Energy Project, Ministry of Water Resources, Irrigation and Electricity (Sudan) to conduct a study to update the Renewable Energy Master Plan, which prepared earlier by Lahmeyer International in 2012. The planning horizon selected is 15 years from 2019 to 2033, with a total proposed capacity of 4050 MW the Renewable Energy Master Plan [15].

REMP UPDATE: CAPACITY, ENERGY, LOCATION & INVESTMENT

Table -3: Plan (2020 – 2021)

Item		2020	MW	GWh	2021	MW	GWh
		Invest / LCOE	mio $ US	$US/kWh	Invest / LCOE	mio $ US	$US/kWh
CAPACITY DEVELOPMENT	Wind capacity and location	Wind -Dongola 100 / Wind - Nyala 50	150	459.9	Wind - Dongola 100 / Wind - Khartoum100 / Red Sea 100	300	919.8
	Wind Investment	$950/kW $0.05/kwh	142.50	0.050	$950/kW $0.05/kwh	285.00	0.050
	PV grid capacity and location	Omdurman 200 / Al-Ghobush 190 / Al-Fashir 5 / Al-Diein 5	400	700.8	Khartoum 200 / El-Obaid 200	400	700.8
	PV grid Investment	$800/kW $0.06/kwh	320	0.060	$800/kW $0.06/kwh	320	0.060

Table -4: Plan (2022 – 2023)

2022	MW	GWh	2023	MW	GWh
Invest / LCOE	mio $ US	$US/kWh	Invest / LCOE	mio $ US	$US/kWh
Red Sea 150 / River Nile 150	300	919.8			
$950/kW $0.05/kwh	285.00	0.050			
			River Nile 200 / Red Sea 200	400	700.8
			$800/kW $0.06/kwh	320	0.060

Table -5: Plan (2025 and 2028)

2025	MW	GWh	2028	MW	GWh
Invest / LCOE	mio $ US	$US/kWh	Invest / LCOE	mio $ US	$US/kWh
River Nile 150 / Niyala 15	300	919.8	Dongola 300	300	919.8
$950/kW $0.05/kwl	285	0.05	$950/kW $0.05/kw	285	0.05
Dongola 200 / Khartoum area 200	400	700.8	El-Obaid 200 / Darfour 200	400	700.8
$800/kW $0.06/kwh	320	0.060	$800/kW $0.06/kwh	320	0.060

Table -6: Plan 2031

2031	MW	GWh	MW_SUM	GWh_SUM
Invest / LCOE	mio $ US	$US/kWh	investment mio $ US	n $US/kWh
River Nile 300	300	919.8	**1650**	5058.900
$950/kW $0.05/kwh	285	0.05	1,567.50	0.050
Khartoum/Gazira Area 200/ River Nile 200	400	700.8	**2400**	4204.800
$800/kW $0.06/kwh	320	0.060	1920	0.060

3. CONCLUSIONS

In conclusion Energy development in Sudan has always been slow and the current generation is far less than the demand only covers less than half of the total demand due to many reasons one of them lack of projects financing for convention or renewable energy generation, although Sudan has been considered as one of the best countries for exploiting solar energy since its average sunshine duration ranges from 8.5 to 11 hours a day.

The electrical energy sectors including renewable energy in Sudan is greatly affected by the presence of monopoly structures, and this monopoly is known to be highly inflexible and hardly gives the private sector access to energy markets. Due to unclear blurry vision for planning in the last years, the energy security in Sudan faced with risk and unsecured situation and characterized by the lack of transparency in projects handling.

The possible solutions for enhancing developing of Sustainable Energy in Sudan is by ratification and approval of renewable energy laws and regulations that incorporate policies and mechanisms which are recommended and attractive to the private sectors, these attracted regulations can be summarized in employing renewable energy targets; expanding Rural Electrification Programs; deploying feed-in tariffs; integrating Clean Development Mechanisms (CDMs); phasing out monopoly power utilities; international assistance and tax incentives

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