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Unlocking Nigeria's Solar PV and CSP Potentials for Sustainable Electricity Development

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Abstract: Nigeria is reasonably endowed with intensity of solar energy which can be transformed into electrical energy through the use of either solar Photovoltaicor Concentrating Solar Power. The potentials range between 3.5 – 7.0 kWh/m2/day, the estimated totalpotential for solar PV of 1% area of some twenty selected states is computed at 1189321.65MWh. The minimum direct normal irradiance is in the range of 4.1 – 5.0 kWh/m2/day in the north with the highest in north-east part of the country, which has met the minimum DNI threshold of 4.1 – 5.8kWh/m2/day needed for economically viable concentrating solar power project. The total potential CSP capacity for the fourteen frontline northern states is estimated at 427,829 MW and the electricity potential at 26,841 TWh/yr. The proper harnessing and utilization of this abundant renewable energy formwould not only serve as long term solution to the looming problems of energy shortages, environmental sustainability and reversals of the low per capita electricity consumption of 121 in the country, but will no doubt lead to rapid transformation of the nation's socio-economic well-being of the citizenry. Thus, high initial investment cost and lack of adequate technical know-how and skilled manpower are identified asbarriers to deployment of this emerging technology in the country. Sound policies, feed-in tariffs, technology transfer and collaboration with industry leaders are proposed as some of the solutions to overcome those challenges enumerated. This paper attempts to review the abundant solar energy potentials of the country and the need to effectively develop it in other to overcome the current electricity poverty facing the nation.

Key words: Concentrating Solar Power, Direct Normal Irradiance,Electricity, Environment, Photovoltaic, Renewable, Sustainability.

1.0 INTRODUCTION:

Nigeria is currently faced with acute problems in the supply of electricity, which has tremendously hindered its development despite the nation's vast natural resources. Power generation facilities are either in poor shape or have inadequate gas supply. Also, the transmission and distribution networks are poorly maintained and inefficiently operated thereby making it difficult to move power from generation sites to consumption points.An analysis of the power generation capacity required to support the Nigeria Vision 20:2020 economic vision shows that, Nigeria will need to generate electricity in the range of about 35,000MW by 2020. This is based on the assumption that the country will take low energy intensity (<0.4) growth path. To achieve security of supply, there is urgent need to aggressively pursue the harnessing of the nation's renewable energy resources such as solar, wind and biomass, (Nigeria, Vision 20:2020, 2009).

Continuous and reliable supply of electricity is required for Nigeria's socio-economicdevelopment. With a more rapidly expanding urban-drifted population (NBS report, 2010) and a highly growing electricity demand, a systematic expansion of the electricity generation facilities and other infrastructure development are imperative to match these rising demand.

The emerging solar technologies of PV and CSP holds much promise for a country like Nigeria with plenty of sunshine and clear skies in most parts of the year. Photovoltaic and Concentrated Solar Power are two primary forms of electricity generation using sunlight. These two solar power generation approaches use different technologies, collect different fractions of the solar resources and have different sitting and production capabilities. The capital and running cost of CSP plants vary widely depending on its design and size. Large CSP system requires substantial investment and before such a project is undertaken the best possible information about the quality and reliability of the solar resource data is essential to determine performance of the proposed CSP plant.

Only 22% of the populations in the sub-saharan Africa have access to electricity (AFREC, 2010). The World Bank estimates that Africa needs to invest US $ 30 billion annually to add 7,000 MW for the next twenty years in order to achieve 21st century electrification. Nigeria's current trends in electrical energy supply and use are patently unsustainable both economically and environmentally. Energyrevolution needs to be initiated in which low carbon technologies will play a lead role.

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This paper is further subdivided as follows: Global trends in solar energy technologies and Nigeria's electricity state are discussed in Section 2.0 and 3.0 respectively. Section 4.0 focuses on sustainable electricity development in Nigeria, Section 5.0 deals with solar PV and CSP potentials in Nigeria. Target markets and Cost related issue; Electricity from Solar PV and CSP, Challenges of solar PV and CSP deployment and Conclusion are discussed in this order Section 6.0, 7.0, 8.0 and 9.0.

2.0 GLOBAL TRENDS IN SOLAR ENERGY TECHNOLOGIES

As the World looks for low-carbon sources of energy, solar power stands out as the single most abundant energy resources on earth. Solar energy is almost inexhaustible. About 1,080,000,000 TWh of power arrive on the earth from the sun each year which is almost sixty thousand times the World electricity requirement. Global production of photovoltaic cells and modules in year 2009 was 9.2 GW.The concentrating solar power technology has been taking off recently. According to a new market report by CSP Today and Altran, concentrating solar power growth in the next 10 years will be concentrated in two key markets, Spain and United States of America. According to Global Concentrated Solar Power Industry Report, most new projects under construction (88%) are located in Spain. It has fifty projects in the works and will be generating 2 GW from CSP by year 2015. Further, growth is expected across markets in the Middle East and North Africa such as Israel, UAE, Morocco, Algeria and Egypt.

CSP currently makes up 679 MW of installed capacity and more than 2000 MW under construction worldwide. The investment in the technology will reach about 2.8 billion dollars this year, (Green Peace International). Based on current global plans, by year 2017, close to 20 GW of CSP capacities will be installed. It is projected that by year 2050 about 15% of Europe's electricity demand could be met through the import of solar energy from North Africa and the Middle East, (Solar Millennium AG).

In Africa the total installed electricity generation capacity in the continent is about 117 GW, while the real demand to satisfy the needs of over one billion population is about 335 GW. This demand will jump to 584 GW by 2030 and to 984 GW by 2050, with growth rate of 2.8% annually, (Elhag, H. 2011). This challengecoupledwith the issue of climate change will force most global energy plans to reconsider their strategies, for the sake of achieving sustainability in their economies and energy development. Therefore, the introduction of renewable-based power is not an option, it is a necessity.

3.0 NIGERIA'S ELECTRICITY STATE

Nigeria which has a teeming population of over one hundred and sixty million people (CBN report, 2010), suffers a severe shortage of electricity generation capacity with electric power consumption (KWh per capita) of 121.51 in 2009 (World Bank report, 2010).This low power generation capacity, falls short of national demand, thus resulting in massive load shedding. Most of the generation facilities are old and obsolete, while maintenance is delayed and inadequate. Compounding the situation further, is the fact that demand for electricity in the country continues to rise and is fast outpacing increases in supply capacity.

The power reform committee set up by the previous successive government, summarizes the poor performance of the sector to lack of adequate and planned investment to add to existing capacity for decades, while demand for electricity rose rapidly due to increased manufacturing capacity, constant population growth and rapid urbanization. Ageing installations led to declining output and efficiency, while failure to overhaul plants and equipments as at when due, coupled with little or no replacement reduced most of the power plants to less than 30% capacity utilization.Transmission network are not spared by series of problems belittling the sector. The country's transmission network (made up of 4,889.2km of 330kV; 6,319.33km of 132kV; 62.5 km of 66kV and sub-stations consisting 21No. 330/132kV with total capacity at 6,098MVA, 99No. 132/33/11kV with total capacity at 8,107.5MVA) is weak. The collective transmission network cannot support more than 3000MW wheeling without interruption.

Currently, there are 11 distribution companies in Nigeria. The distribution network is in deplorable state arising from; (i) Faulty distribution transformers and vandalized lines. This leaves many customers without supply, (ii) Overloaded 33kV and 11kV lines, distribution transformers, feeder pillars and LT lines. The implication of this is that several customers are on power supply rationing during peak load periods, (iii) Aged and obsolete equipment whose performances can no longer be guaranteed. Some of these equipments have been phased out by their manufacturers, thus making spare parts unavailable.

Government commenced the reform of the power sector via the enactment of the Electric Power Sector Reform Act 2005, as a primary driver towards sustainable and adequate power supply to the country. However, the relatively slow pace of the implementation of this Act has not brought the desired changes in the sector. The Act provides for the following among other things: (i) Unbundling of PHCN into six generation, 11 Distribution and 1 transmission companies, (ii) Establishment of Nigerian Electricity Regulatory Commission to regulate and license electricity market participants, (iii) Establishment of Rural

Electrification Agency to expand access to electricity in the rural areas.Further, National Integrated Power Project with an estimated capacity of 2744MW contracts is awarded with different completion timelines. Also, other Independent Power Producers projects and expansion of transmission capacity are ongoing in the country.

4.0 SUSTAINABLE ELECTRICITY DEVELOPMENT IN NIGERIA

The strategic context of electricity in national development cannot be overemphasized. Electricity is a critical infrastructure for sustainable economic growth and development. The inadequate provision of electricity has had a pervasive impact on socio-economic activities and consequently the living standard of the citizenry. In spite of the abundant energy resources in the country and the huge Government investments in the sector over the years, electricity supply remains a serious challenge. Currently, only about 40 per cent of Nigeria's total population has access to public electricity supply due to inadequate transmission, distribution networks, ageing infrastructure as stated above.

In the medium term, the goal is to generate, transmit and distribute 16,000MW of electricity by 2013. Access to electricity is expected to increase from the current 40 per cent to 50 per cent, while per capita consumption will increase from about 120kWh to 500kWh over the plan period. Still, Nigeria's per capita electricity consumption will be by far less than South Africa's year 2009 average of 4,532kWh per capita then, (Table 1).

Table 1: Africa'sComparative Per Capita Electricity Consumption

Country	kWh per capita
Angola	202
Botswana	1,503
Egypt	1,549
Ghana	265
Nigeria	121
South Africa	4,532

Source: World Bank 2010 report(data.worldbank.org)

Conventional energy sources like petroleum, coal and natural gas have proven to be both highly effective drivers of the economic progress, and damaging at the same time to the environment and to human health. Environmental issues, principally climate change, have become serious drivers for transformation in the global energy arena. In this regard the sustainability and environmental friendliness of renewable energy is therefore very significant. Reliable and clean electricity supply is a pre-requisite for sustainable socio-economic development of Nigeria.

In an attempt to achieve sustainable supply of energy and electricity, the Draft National Energy Master Plan (NEMP) and the Renewable Energy Master Plan (REMP),although still awaiting legislation was produced by the Energy Commission of Nigeria in collaboration with donor agencies in year 2007 and 2005 respectively. This is an offshoot of the National Energy Policy (NEP) approved in April 2003 by the Federal Government. It is an overall policy from which all other sub-sectoral energy policies should be drawn from. Its main thrust is the optimal utilization of all the nation's energy resources for sustainable development with substantial private sector participation. Solar PV and CSP,if effectively harnessed in the country, will no doubt be viable solutions to the electricity challenges of Nigeria especially in the rural areas of the country and to the restrictions posed by the rising cost of conventional or traditional energy sources.

5.0 NIGERIA'S SOLAR PV AND CSP POTENTIALS

Nigeria lies within a high sunshine belt and thus has enormous solar energy potentials. It has an average daily sunshine of 6.25 hours, ranging between about 3.5 hours at coastal areas to 9.0 hours at far north. The country has an average of about 5.25 $kWh/m^2/day$ of solar radiation annually, varying from 3.5 $kWh/m^2/day$ in the coastal latitude to 7.0 $kWh/m^2/day$ in the far north. Nigeria receives about 4.851x 1012 kWh of energy per day from the sun, (Okafor, E.C.N. et al, 2010). This is equivalent to about 1.082 million tonnes of oil equivalent (Mtoe) per day. Based on the land area of 924 x 103 km^2 for the country and an average of 5.535 $kWh/m^2/day$, Nigeria has an average of 1.804 x 1015 kWh of incident solar energy annually.

This annual solar energy insolation value is about 27 times the nation total conventional energy resources in energy units and is over 117,000 times the amount of electric power generated in the country. In other words, about 3.7% only of the national land area is needed to be utilized in order to collect from the sun an amount of energy equal to the nation's conventional energy reserve, (Okafor, E.N.C. and Joe-Uzuegbu, C.K.A., 2010).

5.1 Solar Photovoltaic

Solar radiation is fairly distributed in Nigeria, almost everywhere is suitable for solar PV application. The potential ranges between 3.5 – 7.0 $kWh/m^2/day$ with peak radiation at north eastern partof the country.The average solar radiation for 1% area of the state is computed by multiplying 1% of total area by the lower limit of the range where the state falls. Table 2 gives summary of an estimated range of solar PV potential of some twenty selected states in Nigeria put at 1189321.65MWh.

Table 2: Estimated Solar PV potentials of Nigeria

	STATE	AREA (km^2)	1% OF AREA (km^2)	MAX. POWER POTENTIAL FOR 1% AREA (MWh)
6.5 - 7.0 $kWh/m^2/day$	Sokoto	32146	321.46	53040.9
	Katsina	23822	238.22	39306.3
	Jigawa	23415	234.15	38634.75
	Yobe	44880	448.80	74052
	Borno	72767	727.67	120065.55
	Kano	20389	203.89	33641.85
	Zamfara	33667	336.67	55550.55
	TOTAL			414291.9

	STATE	AREA (km^2)	1% OF AREA (km^2)	MAX. POWER POTENTIAL FOR 1% AREA (MWh)
6.0 - 6.5 $kWh/m^2/day$	Adamawa	37957	379.57	62629.05
	Gombe	17428	174.28	28756.2
	Bauchi	48197	481.97	79525.05
	Kaduna	44217	442.17	72958.05
	Niger	72065	720.65	118907.25
	Kebbi	36320	363.20	59928
	FCT	7569	75.69	12488.85
	Plateau	26539	265.39	43789.35
	TOTAL			478981.8

5.5 - 6.0 kWh/m²/day	STATE	AREA (km²)	1% of AREA (km²)	MAX. POWER POTENTIAL for 1% AREA (MWh)
	Nasarawa	26633	266.33	43944.45
	Taraba	59180	591.80	97647
	Kwara	33792	337.92	55756.8
	Kogi	29063	290.63	47953.95
	Benue	30755	307.55	50745.75
	TOTAL			296047.95
GRAND TOTAL				1189321.65

Source: Radiation Range from Africa Flat Plate Tilted at Latitude, Annual. NREL, UNEP, Nov 2005.

Note: Using 220Wp PV panel with an area of 4m2 at PSH of 5kWh/m2/day and performance ratio of 0.6.

5.2 Solar CSP

An area is considered eligible for solar CSP application when it receives minimum direct normal irradiance (fraction of sunlight that is not absorbed or reflected by the atmosphere) of 4.1 kWh/m²/day. Normally, the land slope threshold for CSP excludes areas greater than three degree.

Northern Nigeria with DNI above 4.1 kWh/m²/day is considered suitable for CSP application because of its relatively flat terrain. Table 3 summarizes the potential CSP capacity of some selected states which indicates high potential.

Table 3: Estimated Solar CSP potential of selected 10 states in Nigeria.

SELECTED STATES	DNI AREA	DNI AREA WITH SLOPE < 3% (km²)	ELIGIBLE (km²)	POTENTIAL ELECTRICITY PRODUCTIONTWh/ year	POTENTIAL CSP CAPACITY (MW)
Adamawa	50%	9,489	474	857	14,233
Bauchi	100%	14,459	722	1,306	21,688
Borno	100%	65,490	3,274	6,991	98,235
Gombe	95%	13,245	662	1,196	19,867
Jigawa	60%	11,239	561	1,015	16,858
Kaduna	50%	11,054	552	998	16,581

Kano	100%	16,311	815	1,473	24,466
Katsina	90%	17,151	857	1,549	25,727
Kebbi	60%	17,433	871	1,574	26,150
Niger	50%	25,222	1,261	2,278	37,834
Plateau	80%	16,984	849	1,534	25,477
Sokoto	50%	11,251	562	1,016	16,876
Yobe	80%	32,313	1,615	2,919	48,470
Zamfara	100%	23,566	1,178	2,128	35,350
TOTAL				26,841	427,820

Source: Nigeria Climate Assessment, preliminary report (World Bank / Lumina Decision) 2011.
NOTE: 1) Potential is 5% of eligible area.2) Capacity estimated at 50MW/km²

6.0 Target Market andCost related issues

There is no single renewable energy technology, from wind power to solar energy through biofuels thathas remotely become competitive with kilowatt hour of electrical energy generated by conventional fossil fuels. But, looking critically at the nation's total potential CSP capacity alone of 427,820MW, Nigeria cannot afford to ignore diversifying its energy supply mix to include solar energy. If properly harnessed this will no doubt usher in new energy revolution, thereby leading to rapid industrialization and economic stability.
Solar technologies are the most expensive among the renewableswith solar PV beingthe highest and has high initial cost of setting up. However, this high cost is offset by the fact that it requires little maintenance and virtually no fuel cost. The average cost of solar panels ranges from €2.5-3.5 per Wp. Solar PV is mostly used with light loads because the cost of generating large quantity of electricity is unreasonable even in the long run.CSP plants have higher maintenance costs than solar PV plants. The levelisedcost of CSP is about €0.16 per kWh (from the Andasol 1 project which is the first commercial parabolic trough solar thermal plant in Europe with a capacity of 150MW); Table 4 gives comparative levelised cost of electricity.

Table 4: Levelised cost of electricity (LCOE) 5% discount

TECHNOLOGY	**US$ per MWh**
Solar PV	215.45
Solar CSP (thermal)	211.18
Gas fired PP	76.56
Coal-fired PP	72.49
Nuclear	48.73

Source: 2010 IEA Report

7.0 Electricity from Solar PV and CSP

The major components for harnessing electricity from solar are panels in case of photovoltaic and reflectors (mirrors) in case of CSP. It is imperative to conduct a detailed study and survey before setting up a system. A complete geographical study is needed throughout the year with details of sunlight hours, peak sun hours per day, temperature, cloud cover, direct normal irradiation and physical topography of proposed area.

Electricity can be generated directly from solar energy by solar cells. A collection of solar cells makes a panel which is the unit commonly found in the market. The collection of these panels is called a solar array. The most popular solar panels found today are made of polycrystalline silicon, mono-crystalline silicon, amorphous silicon and thin film silicon. The panels are usually mounted on roof tops, poles or free standing on ground and should be free from obstruction, as shadow covering one-fourth of panel can reduce its output by upto 50%. It is very important to mount solar panels and reflectors at the right angle and orientation. The use of solar trackers increases the efficiency of the system. Further, loads factors should be properly ascertained in order to obtain the accurate required configuration.

A complete solar PV system consists of the panels, inverters, batteries and charge controllers. The solar panel converts solar energy to DC electricity, while inverters are needed to convert the DC electricity to AC electricity which most electrical appliances utilize. The batteries are used to

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store electricity during the day for use during periods of little or no generation which is mostly at night. The charge controllers regulate how the batteries are being charged and discharged, thus providing protection for the batteries.

Solar PV system can be grid-tied or off-grid. In grid-tied systems electricity is generated during the day and fed into the grid system directly. Off-grid solar PV system is the most popular. It is mostly used for remote location far away from the grid where extending the grid to such location is not economically viable. The system is not connected to grid but directly fed to final consumers. Excess electricity is stored in batteries for use at night.The solar cell typically has an efficiency of 9-16% and can last for25 years.

The process of generating electricity from CSP is nearly the same with conventional fossil fuel thermal plants with the difference being the fuel source. A typical CSP plant uses reflectors and parabolic mirrors to focus the sun's rays onto a heat collector. Heat transfer fluids such as synthetic oil are used to transfer heat from the collector to heat exchangers where water is super-heated. The super-heated steam runs a turbine which in turn drives a generator to generate electricity.

There are different CSP technologies based on focus type (line and point focus) and receiver type (fixed and mobile). Thus, there is line focus fixed receiver, line focus mobile receiver, point focus fixed receiver and point focus mobile receiver. Most CSP technologies use thermal storage in which excess heat is diverted to storage material such as molten salts. After sunset the molten salt is used as heat transfer fluid for the system. Thermal storage ensures that the turbine can always run at full load and with optimal efficiency, which in turn makes the power plant more profitable.CSP systems are ideal for grid connection, although small off-grid systems can be designed; they are the best suited solar technology that is capable of providing utility scale electricity and are usually used to provide base load power where they exist.

8.0 CHALLENGES

There are various challenges affecting solar PV and CSPdevelopment in the country, some of which include higher initial investment cost as compared to conventional plants of same output, lack of indigenous manufacturing companies, lack of trained personnel installed and maintain existing equipments. Low system efficiency compared to conventional plants. There is little or no generation at night or on cloudy days coupled with lack of adequate storage technology.

9.0CONCLUSION

Growth of solar markets will largely depend on deliberate policies aimed at promoting solar energy on one hand and continued investment in energy infrastructure by both the government and private sector on the other. The need to reduce reliance on fossil fuels is intuitive, as the evidence of climate change is fast manifesting. Provision of tax credits for solar energy and related components will tremendously boost the market in the country.

In order to facilitate the off-grid electricity extension especially to the rural and remote areas, there is urgent need to embark on aggressive solar electrification projects all over the country. Further, continuous active support in research and development activities to cater for site specificity of designs for all parts of the country, demonstration and pilot projects to ensure that the general public is aware of the potentials of solar energy technologies will greatly assist in creation of markets for solar energy systems.Availability of affordable and clean electricity in the country will have a significant input in cutting CO_2 emissions, thereby leading to improvement in the quality of life of the citizenry. If Nigeria can effectively harness its solar potential for thermal power plants, it can transform from being an oil-rich to solar-rich nation.

REFERENCE

[1] *Agha, K., 2011: Solar Radiation Assessment, Training Workshop on Concentrating Solar Power Technologies for*

[2] *electricity, Generation in Africa, AFREC-AU-ECN, Abuja, Nigeria.*

[3] *Elhag, H., 2011: Mapping Solar Energy Resources of Africa, Training Workshop on Concentrating Solar Power*

[4] *Technologies for electricity Generation in Africa, AFREC-AU-ECN, Abuja, Nigeria*

[5] *Central Bank of Nigeria, Annual Statistical Bulletin and report, 2010, Abuja, Nigeria.*

[6] *Energy Commission of Nigeria, Draft National Energy Masterplan, 2007.*

[7] *Energy Commission of Nigeria, Renewable Energy Masterplan, 2005.*

[8] *Franz Trieb et al, 2009: Global Potential of Concentrating Solar Power, Solar Paces Conference, Berlin, Germany.*

[9] *Gary, G. and Kristen, D.; 2008: Concentrating Solar Power, Clean Energy for the Electric Grid,*

[10] *International Energy Agency report, 2010: Projected Cost of Generating Electricity, Paris, France.*

[11] *International Energy Agency, 2010: Technology RoadMap, Concentrating Solar Power, Paris, France*

[12] *National Bureau of Statistics report, 2010, Nigeria.*

[13] *National Planning Commission, Nigerian Vision 20:2020; 2009: Abuja, Nigeria*

[14] *Nigeria Climate Change Assessment, 2011: World Bank Presentation on Low Carbon Plan- Power Sector, Abuja, Nig.*

[15] *Nigerian Power Reform Committee, Final Report 2008*

[16] *Okafor, E.C.N &Joe- Uzuegbu, 201): Challenges to development of renewable energy for electric power sectorin Nigeria. International Journal of academic research Vol. 2, No. 2.*

[17] www.data.worldbank.org (World Bank report, 2009)

[18] www.ecogreek.org/solar-power (Green Peace International)

[19] www.nrel.gov/docs/gen/fy04/36831.pdf

[20] www.solarmillennium.de