

Investigating Impact and Viability of Hostile Weather Conditions on Solar Farm Establishment in Nigeria: A Case Study

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Abstract— The study investigates impact of hostile weather conditions on performance and viability of solar farm establishment in Nigeria. This was done on two different PV Modules of 10MW capacity using NASA radiation data for six (6) different locations (Abuja, Birnin-Kebbi, Enugu, Lagos, Port Harcourt and Maiduguri) in Nigeria. RETScreen clean energy software was used in the simulation. The results show dependence of Capacity Utilization Factor (CUF) on Solar Irradiation among other design and technological factors like Controlled tracking of PV Module and type. Other Factors like air temperature, wind speed, elevation from horizon and latitude of the location that affect irradiation are also investigated. The findings showed that increasing the output of the system by increasing the capacity of PV module does not affect CUF but attract additional cost, thus making solar farm in hostile environment costly.

Index Terms—Wether, CUF, Farms, PV

I. INTRODUCTION

Generating power by converting sunlight into electricity is not a new concept; neither is generating solar power at the utility scale. What is new, however, is the accelerating demand for clean energy, particularly PV solar energy. Solar energy as one of the many sources of renewable energy-based off-grid electricity supply is traditionally considered as an expensive and unreliable source of power. But as technology improves over the years, renewable energy sources are beginning to take the stage of modern energy divide (Omorogiuwa Eseosa and Ekiyor Martin Thompson 2017). The modern surge for solar is, in part, driven by rising demand for electricity and increasing environmental costs associated with conventional fuels. In recent years, large-scale solar energy development has also been invigorated by the economic forces of technological innovation, falling costs of production, and political support in the way of renewable energy standards and goals. As a result, numerous large-scale solar projects have taken root domestically and internationally, and are continuing to grow. However, solar energy usage has not gained much popularity in Nigeria as it is majorly limited to pilot and demonstration projects even with abundant available solar renewable energy. Solar energy applications serve various energy needs among rural dwellers because of obvious deprivation of grid supply. Solar PV technologies are growing, though awareness is relatively low. PV installations are commonly found in street lighting, rural electrification projects as well as low and medium level uses such as solar pumps. PV cells have been installed to serve rural clinic and schools. Understandably, many of the earliest projects were developed in areas where

sun shines the most. Northern Region of Nigeria is certainly very viable for solar development for many reasons: land is relatively cheap, environmental impacts tend to be less complex, population is comparatively less dense, high solar irradiance, low humidity, and the weather is predictably cloudless for most part of the year. Though the conditions in the North are rather ideal, large-scale solar power is still very much a viable source of renewable energy in a myriad of conditions and locations. In other regions of Nigeria, particularly in the South, for instance, the conditions are dramatically different from the North—land tends to be expensive, very complex environmental impacts, denser population, solar irradiance is comparatively less, humidity can soar, and the weather is highly variable and extremely difficult to predict. Even though the conditions may not be as ideal as those found in the North, economic forces are spurring the feasibility of PV solar power development in other regions of Nigeria. However, a predictive study of the performance of solar PV system in various locations in Nigeria will result in correct investment decisions, better regulatory framework and favorable government policies. Accurate and consistent evaluation of PV system performance allows detection of operational problem, facilitate the comparison of system that may differ with respect to design, technology, or geographic location and validate model for system performance and cost estimation during the design phase. A comparative analysis of the meteorological Data across regions in Nigeria is necessary to determine variation of solar irradiation and its effect on solar energy utilization in Nigeria. Solar Energy depends on solar radiation which is a lot more complex than human perception of solar potential from sunshine and may require sophisticated instrument for measurement. Moreover, to successfully investigate the distribution of solar resources in Nigeria, more regions than North and South will be under studied. Optimum Solar PV system is derived with regard to various designs and technologies, thus resulting to correct investment decision and performance improvement. It will also facilitate comparison of systems that may defer with respect to geographic location among others and validate models for system performance. This work overviews environmental constraint of utility solar PV energy utilization in Nigeria in an attempt to achieve the following:

- Review design and technological criteria for better performance of solar power plants.
- Determination of viability of solar power potentials at different locations in Nigeria
- Modeling of PV systems using RETScreen renewable

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energy software and make possible recommendation for future work in the field of solar energy

II. REVIEW OF RELATED WORK

PV panels have been used to collect photons for decades with the sole purpose of generating power for utilities since the first megawatt- scale solar farm was built in Sacramento, California, in 1984 (Green Energy News 2009) as cited by Robert and Anders (2013). From the location of Nigeria, it can actually produce appreciable amount of solar energy radiation as this value varies across the country from 3.5kWh/m² per day in the coaster latitude to 7kWh/m² per day in the far North; giving an annual average solar intensity estimated to be 1934.5kWh/m². (Akindele, 2014). According to Sambo, 2009 as cited by Akindele (2014), with 1% of Nigeria's land area covered by solar collectors, given prevailing efficiencies and average radiation of 5.5kWh/m²/day, it will be possible to generate 1850x10³ GWh of electricity per year, which is over 100 times grid consumption level. However, there is currently no grid input from solar source in Nigeria. In recent years, studies of solar energy technology are on the rise as it becomes more readily deployable as in the case of Ethiopia rural electrification where SPV account for 95% electrical energy of HPS (Zelalem, 2013). In the author's methodology, to obtain PV arrays/size that will satisfy energy demand, parameters used include lifetime PV array of 25 years, 90% derating factor and ground reflectance of 20% and was simulated with homer optimization software. The results showed that the site has tremendous solar resource potential, with average radiation of 6kWh/m²/day (insolation). This is the reason 95% of electrical energy is from PV array while the rest 5% is obtained from diesel Generator in optimum system. The author also concluded that incentives from state and federal government are critical to the widespread deployment of such system due to high net present cost. The method adopted by Emmanuel (2009) to analytically calculate various losses of PV Park considered in-plane solar radiation, ambient daytime temperature, array DC power as well as park AC output power averaged with 10 min frequency during a typical day per month. The nominal instantaneous array DC power per 10 min and total annual array output energy were computed using solar radiation data as well as technical specifications of photovoltaic panels. Real array output power obtained by gradually adding various losses of array comprising of degradation modulus, temperature and soiling losses. The same method is adopted for calculation of interconnection, inverter and transformer losses by correlating real array power output with PV park power output with a 10 min frequency. This method gives realistic estimate, since various losses are interrelated and directly linked with instantaneous real power output of both PV panels and park.

The efficiency of PV panel depends on the operating temperature and power density of solar radiation. As its temperature increases, efficiency decreases linearly, since peak power PV panels refers to Standard Test Condition (STC). In different temperatures, output power of PV panels depends on difference of panel temperature, STC temperature (TC -TSTC) and power density (G) of the incident solar radiation. The following variables were defined by the researcher; final yield (YF), reference yield (YR), performance ratio (PR) and capacity factor (CF) and were

calculated as defined by IEC Standard 61724. The final yield is annual, monthly or daily net AC energy output of the system divided by peak power of installed PV array at STC of 1000 W/m² solar irradiance and 25-degree cell temperature.

$$YF = \frac{E_{[KWh_{A,C}]}}{P_r [KW_{DC}]} \quad 1$$

Reference yield is the total in-plane solar insolation Ht (kWh/m²) divided by the array reference irradiance (1 kW/m²); therefore, the reference yield is the number of peak sun-hours.

$$Y_R = \frac{Ht [KWh/m^2]}{1KW/m^2} \quad 2$$

Performance ratio is the final yield divided by reference yield. It represents the total system losses when converting from name plate DC rating to AC output. The typical losses of PV park include losses due to panel degradation(η_{deg}), temperature(η_{tem}),soiling(η_{soil}), internal network(η_{net}), inverter(η_{inv}), transformer (η_{tran}), system availability and grid connection network (η_{ppc}). Therefore, PR can be expressed as

$$P_R = \frac{Y_F}{Y_R} = \eta_{deg} \cdot \eta_{tem} \cdot \eta_{soil} \cdot \eta_{net} \cdot \eta_{inv} \cdot \eta_{tran} \cdot \eta_{ppc} \quad 3$$

Array yield (YA) is defined as annual or daily energy output of the PV array divided by the peak power of the installed PV. System losses (LS) are gained from the inverter and transformer conversion losses, and the array capture losses (LC) are due to the PV array losses

$$Y_A = \frac{E_A}{P_r} \quad 4$$

$$L_C = Y_R - Y_A \quad 5$$

$$L_S = Y_A - Y_F \quad 6$$

Finally, capacity factor (CF) is defined as the ratio of actual annual energy output to the amount of energy PV Park would generate if operated at full power (Pr) for 24hr/day for a year.

$$C_F = \frac{Y_F}{8760} = \frac{E}{P_r \times 8760} = \frac{Ht \times P_R}{P_r \times 8760} \quad 7$$

Performance ratio and various power losses associated with 5MW Grid connected solar PV power plant in Karnataka were evaluated over 7-months period. Manually extracted parameter through SCADA system was compared with simulated result from PVsyst software. The closeness of the result proves the method satisfactory for determining possible plant capacity for an arbitrary chosen area. (Bharathkumar and Byregowda, 2007).

Hakeem in 2013 categorized PV systems on the basis of their functional operational requirements, component configuration and equipment connection to other power sources and electrical loads. On these basis, PV systems are rather classified as grid-connected/utility-interactive systems and stand-alone systems. Marion et al (2005) presented a paper to illustrate the extent to which the performance parameters of grid connected solar PV plant might be influenced by weather. PV system performance was modeled using PV form for 30-year period. The hourly solar radiation

and meteorological data input to PV form was for the boulder, CO₂ Station in the National solar radiation Data base. Final yield (Y_f) shows the greatest variability and the PVUSA rating at PTC shows the least. The variability of the reference yield (Y_r) is similar to the final yield because of Y_r dependence on solar irradiance. Performance Ratio (PR) values exhibit the influence of temperature, with smaller values in summer than winter for every yearly values. Both PVUSA, AC power rating at PTC and yearly PR values should be able to detect degradation of system performance over time.

Dirk and Sarah (2012) presented a report on 40-year field test on module degradation rate. Nearly 2000 degradation rate measured on individual module or entire system, have been assembled from literatures and showed mean degradation rate of 0.8%/year and a median value of 0.5%/year. The majority (78%) of all data reported a degradation rate of <1%/year. Significant differences between module and system degradation rates observed earlier on has narrowed, implying that substantial improvement towards stability of the balance of system components has been a choice. Despite the progress achieved in the last decade, linearity and precise impact of climate have not been satisfactorily determined.

III. METHODOLOGY

RETScreen is the choice software used for the study. It is clean energy project analysis software used in energy decision making and allows engineers, architects, and financial planners to model and analyze any clean energy project. It allows five step standard analyses. These include energy analysis, cost analysis, emission analysis, financial analysis and sensitivity/risk analysis. RETScreen is used in this report to predict the output from 10MW power plant using satellite data from National Aeronautics and Space Administration (NASA) in the absence of real time measurement from solar plant and metrological site in Nigeria. In order to determine environmental hostilities of solar PV performance in Nigeria, information and data from a wide variety of sources (primary and secondary) such as Data from solar radiation was obtained from NASA and analyzed using RETScreen software to determine irradiation levels from different sources, and power output from solar plants.

3.1 Data Collection

The following data were collected from NASA.

✓ Geographical and environmental variables associated with solar PV Module in the locations. These include: Latitude & Longitude, Climate Zone, Elevation, Heating Design Temperature, cooling design temperature, Earth Temperature Amplitude, Air Temperature, Relative Humidity, Precipitation, Daily Solar Radiation, Atmospheric Pressure,

Wind Speed, Earth Temperature, Heating Degree-Days and Cooling Degree-days.

✓ Manufacturers' specification Data for two different PV Module (mono crystalline silicon & amorphous silicon) of 10MW each.

3.2 Data Analysis

RETScreen software was used to simulate the geographical, environmental and solar PV module parameters. Data for six locations which uses radiation data from NASA and Ground measurement was obtained and analyzed. It was found that NASA source data varies over a wide range depending on whether it is collected from monitoring stations, extrapolated, or derived from satellite information. In order to evaluate the environmental factors associated with Solar PV performance, technological and design factors are kept constant while factors that are specific to geographical locations are varied. One Location is taken from each of the six geographical zones in Nigeria as climatic variation is minimal within a region. The latitudes at the locations are used as the optimum tilt angle for the PV module in fixed tilt orientation to maximize Irradiation and to ensure same condition for all locations. Simulations was done for both Fixed tilt and Single axis tracking Scheme, leading to a total of 24 simulations with 4 in each location. These include Abuja, Birnin-Kebbi, Enugu, Lagos, Port Harcourt and Maiduguri as highlighted in Figure 3.0. Assumption used in RETScreen for Mono-Silicon and Amorphous Silicon modules are given in Table 3a and 3b respectively.



Figure 3.0 Regional Map of Nigeria

Table 3a: Mono-Silicon Module and inverters parameters.

Photovoltaic		mono-Si	
Type		BP Solar	10
Power capacity	MW	mono-Si - BP 1210	1,000,000
Manufacturer			7.75%
Model			45
Number of units			0.4%
Efficiency	%		129,032
Nominal operating cell temperature	°C		7.5%
Temperature coefficient	% / °C		
Solar collector area	m ²		
Miscellaneous losses	%		
Inverter			
Efficiency	%		96%
Capacity	kW		10,000
Miscellaneous losses	%		0%
Resource Assessment			
Solar Tracking Mode			Fixed and one - Axis
Slope			Latitude of the location
Azimuth			0

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Table 3b: Amorphous Silicon and inverter parameters

Photovoltaic		MW		a-Si	
Type					10
Power capacity					BP Solar
Manufacturer					a-Si - BP Millennia M5T 50 MV
Model					200,000
Number of units					6.1%
Efficiency	%				4%
Nominal operating cell temperature	% / °C				0.11%
Temperature coefficient	% / °C				163,934
Solar collector area	m²				7.5%
Miscellaneous losses	%				
Inverter					
Efficiency	%				96%
Capacity	kW				10,000
Miscellaneous losses	%				0%

Resource Assessment
Solar Tracking Mode
Slope
Azimuth

Fixed and one - Axis
Latitude of the location
0

IV. RESULT AND DISCUSSIONS

RETScreen Simulation result in Table 4.0 shows the trend of

improvement CUF from fixed tilt to single axis tracking and from mono-silicon to amorphous silicon module

Table 4.0: CUF and annual output for tilt and one axis tracking method at various locations.

S/ N	location	Annual Average Radiation KWh/m²/d		Mono-Silicon Annual Output MWh		Amorphous-silicon Annual Output MWh		m-Si CUF		a-Si CUF		Amb Temp °c	Wind Speed (M/s)	Optimum Tilt Degree
		Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking	Fixed Tilt	One - Axis Tracking			
1	Abuja	5.45	6.88	16,460	20,423	17,555	21,791	18.8	23.3	20	24.9	24.7	2.4	9.2
2	Birnin Kebbi	5.97	7.75	17,758	22,599	19,199	24,436	20.3	25.8	21.9	27.9	27.6	2.3	12.5
3	Enugu	4.92	5.97	14,804	17,795	15,733	18,917	16.9	20.3	18	21.6	25.2	2.1	6.3
4	Lagos	4.74	5.69	14,260	16,962	15,155	18,032	16.3	19.4	17.3	20.6	25.7	2.8	6.5
5	Port Harcourt	3.96	4.48	11,907	13,435	12,603	14,222	13.6	15.3	14.4	16.2	26.7	2	4.9
6	Maiduguri	5.89	7.63	17,599	22,313	18,974	24,059	20.1	25.5	21.7	27.5	27	3.8	11.9

The trend is also repetitive in the average radiation across the locations. Average radiation is directly proportional to CUF. Air temperature does not have linear relationship with solar radiation (irradiation) as seen in cases of Port Harcourt and Lagos with lower irradiation despite having higher air Temperature than Abuja and Enugu. Other geographical factors like location latitude, elevation from the horizon and wind velocity also affect the irradiation level. From the meteorological resource data in Appendix A and B, Port Harcourt and Lagos have the lowest elevation with values of 18m and 32m respectively. The irradiation is also observed to have direct variation with the nearness of the latitude to north with exception to Enugu and Lagos. Lagos is 0.2 degree more elevated than Enugu but 155m lower from the horizon. Their latitudes are 6.5 degree and 6.3 degree due north respectively. The irradiation of Enugu is higher than Lagos despite trailing Lagos by 0.2 degree north. The pattern is sustained as the difference in their latitude is small as compared to the difference in their elevation from the horizon.

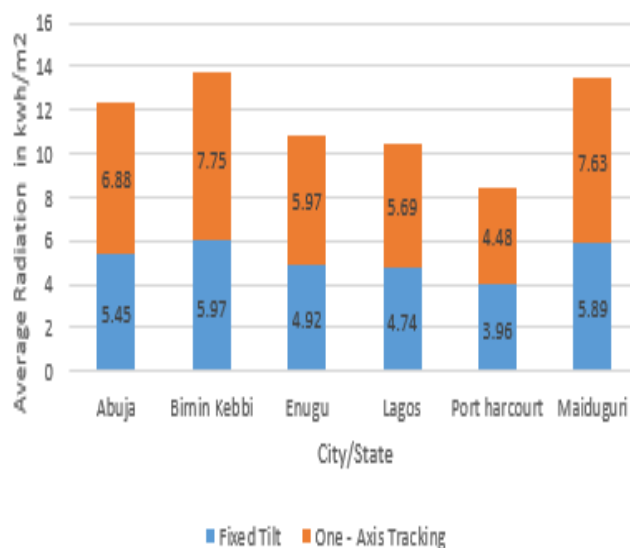


Figure 4.0: Average Radiation for fixed tilt and one axis tracking system on the various locations

There is significant improvement on the annual average radiation by the used of one axis tracking control method in all location as shown in Figure 4.0. Port Harcourt recorded 13.1% increase while Birnin Kebbi shows an increase of 29.8%. Percentage increase is seen to rise from the least average radiation to the highest average radiation. The increase obtained by the use of one axis tracking control is proportional to the magnitude of the fixed tilt average radiation.

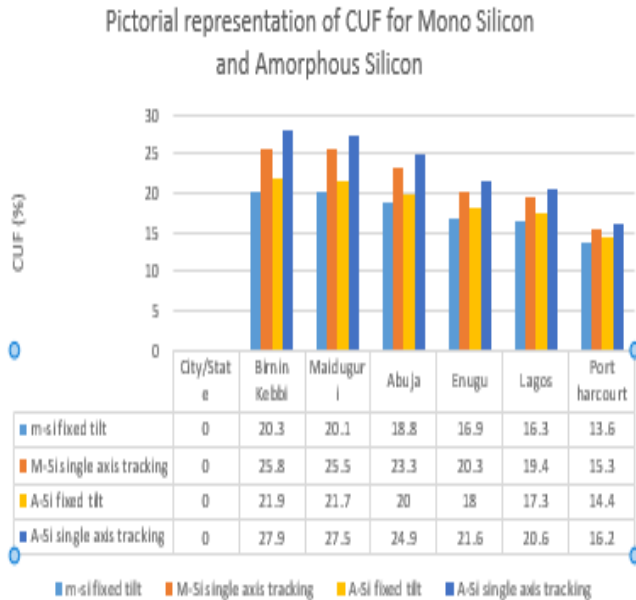


Figure 4.1: Shows CUF for various location, PV Module type and tracking mechanism.

The difference of CUF brought about by PV module type is minimal compare to change in CUF due to the use of tracking scheme. Figure 4.1 shows variation of CUF from the highest to the least across different locations and variations of CUF due to tracking technique and PV module type within a location. Birnin-Kebbi has the highest CUF while Port Harcourt has the lowest CUF. The initial cost, operational and maintenance cost for fixed tilt and single axis tracking scheme are shown in Table 4.1. From the investigation, tracking scheme is more expensive than fixed tilt system both in terms of cost and maintenance.

Table 4.1 Economic Analysis

Cost Summary	Fixed Tilt	Single tracking Axis
Initial cost/KW	\$ 2800	\$ 3400
O & M cost/KW-Year	\$ 38	\$ 44
10MW Initial Cost	\$28,000,000	\$38,000,000
10MW O & M Cost/year	\$380,000	\$440,000

V. CONCLUSION AND RECOMMENDATION

Solar Farm investment will play an important role in the overall energy supply in Nigeria because of its great potential in most location. Among the six towns selected from each of the geopolitical zones only Port Harcourt and Lagos shows low solar potential as determined from their CUF. This depends on several factors including Solar Radiation, Temperature, Air Velocity, apart from technological and

design Parameters like, PV Module type and quality, angle of tilt (or tracking), Cable losses, efficiencies of Inverter and Transformers. Amorphous Silicon PV Module performed better than Mono Silicon PV Module in all the locations but did not improve the CUF as much as the variation of tracking mechanism, from fixed tilt to single axis tracking scheme. Annual output of Solar PV farm can be improved considerably by increasing the capacity of Solar PV Module and reducing losses in cable, inverter, transformer and soiling. In the case of Port Harcourt, to achieve an output of 28,444MWh/year, Solar PV Module capacity will be increased to 20MW, which is twice the initial capacity. Simulation results for 20MW in Port Harcourt are shown in Appendix C and D. This will require an additional initial and maintenance cost of \$38,000,000 and \$440,000/year respectively. The overall effect results in increasing cost. Furthermore, the use of storage facility to compliment the output in period of low solar irradiation will also attract additional cost, thereby making solar farm in hostile environment feasible but costlier.

It will be desirable to monitor solar radiation data from ground base weather station in order to determine the inaccuracies associated with satellite measured data such as that provided by NASA, NREL and WRDC. This work is essential in providing useful proposition to the application of solar energy technology to meet the millennium development Goal (MDG) of clean energy deployment in Nigeria. This paper is limited to investigation of Environmental factors affecting Solar PV performance in Nigeria. The factors considered are those specific to a given geographic location. It also encompasses models for system comparison, performance analysis and cost estimation during the design phase. It does not include other factors like module degradation, capture losses, and losses in system inter-connectivity. It is also recommended to carry out detailed study for several locations with active involvement of existing Solar plant in the region.

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Appendix A

Enugu, Port Harcourt and Lagos Meteorological Resource Data

RETScreen - Climate database				
Country	Nigeria			
Province/State				
Climate data location	Enugu			
Latitude	°N	6.3		
Longitude	°E	7.5		
Climate zone	1A	Very hot - Humid		Source
Elevation	m	187		NASA
Heating design temperature	°C	20.2		NASA
Cooling design temperature	°C	31.1		NASA
Earth temperature amplitude	°C	10.5		NASA

RETScreen - Climate database				
Country	Nigeria			
Province/State				
Climate data location	Port Harcourt			
Latitude	°N	4.9		
Longitude	°E	7.0		
Climate zone	0A	Extremely hot - Humid		Source
Elevation	m	18		Ground + NASA
Heating design temperature	°C	22.3		NASA
Cooling design temperature	°C	28.3		NASA
Earth temperature amplitude	°C	4.2		NASA

RETScreen - Climate database				
Country	Nigeria			
Province/State				
Climate data location	Lagos			
Latitude	°N	6.5		
Longitude	°E	3.5		
Climate zone	1A	Very hot - Humid		Source
Elevation	m	32.2		NASA
Heating design temperature	°C	22.4		NASA
Cooling design temperature	°C	29.0		NASA
Earth temperature amplitude	°C	5.2		NASA

Appendix B

Meteorological Resource Data for Maiduguri, Birnin Kebbi & Abuja

RETScreen - Climate database				
Country	Nigeria			
Province/State				
Climate data location	Maiduguri			
Latitude	°N	11.9		
Longitude	°E	13.2		
Climate zone	0B	Extremely hot - Dry		Source
Elevation	m	337		NASA
Heating design temperature	°C	17.4		NASA
Cooling design temperature	°C	36.8		NASA
Earth temperature amplitude	°C	18.5		NASA

RETScreen - Climate database				
Country	Nigeria			
Province/State				
Climate data location	Birnin Kebbi			
Latitude	°N	12.5		
Longitude	°E	4.2		
Climate zone	0B	Extremely hot - Dry		Source
Elevation	m	263		NASA
Heating design temperature	°C	18.3		NASA
Cooling design temperature	°C	37.7		NASA
Earth temperature amplitude	°C	18.1		NASA

RETScreen - Climate database			
Country	Nigeria		
Province/State			
Climate data location	See map	Abuja	
Latitude	°N	9.2	
Longitude	°E	7.2	
Climate zone	1A	Very hot - Humid	Source
Elevation	m	573	NASA
Heating design temperature	°C	18.3	NASA
Cooling design temperature	°C	32.8	NASA
Earth temperature amplitude	°C	13.6	NASA

Appendix C

Port Harcourt Simulation Parameters for 20MW

Photovoltaic			
Type		a-Si	
Power capacity	MW	20	
Manufacturer		BP Solar	
Model		a-Si - BP Millenia MST 50 MV	
Number of units		400,000	
Efficiency	%	6.1%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.11%	
Solar collector area	m ²	327,869	
Miscellaneous losses	%	7.5%	
Inverter			
Efficiency	%	96%	
Capacity	kW	20,000	
Miscellaneous losses	%	0%	
Summary			
Capacity factor	%	16.2%	
Initial costs	\$/kW	3,400	
	\$	68,000,000	
O&M costs (savings)	\$/kW-year	44	
	\$	880,000	
Electricity export rate		Electricity exported to grid - annual	
	\$/kWh	0.10	
Electricity exported to grid	MWh	28,444	
Electricity export revenue	\$	2,844,393	

Appendix D

Port Harcourt simulation Result for 20MW

Resource assessment

Solar tracking mode

Slope

Azimuth

One-axis

4.9

Show data

Month	Daily solar radiation - horizontal kWh/m ² /d	Daily solar radiation - tilted kWh/m ² /d	Electricity export rate \$/kWh	Electricity exported to grid MWh
January	4.13	4.90	0.10	2,639.005
February	4.32	5.06	0.10	2,456.673
March	4.23	4.81	0.10	2,591.109
April	4.29	4.84	0.10	2,521.848
May	4.13	4.61	0.10	2,482.108
June	3.82	4.19	0.10	2,185.119
July	3.51	3.76	0.10	2,034.927
August	3.29	3.46	0.10	1,873.910
September	3.79	4.17	0.10	2,180.834
October	3.89	4.39	0.10	2,372.921
November	3.98	4.64	0.10	2,423.037
December	4.15	4.98	0.10	2,682.441
Annual	3.96	4.48	0.10	28,443.934
Annual solar radiation - horizontal	MWh/m ²	1.44		
Annual solar radiation - tilted	MWh/m ²	1.64		