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Technical and economic evaluation of electricity generation cost from solar photovoltaic technology in Nigeria: A case study of Kano State

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ABSTRACT*: This research study assessed the technical feasibility and commercial profitability of commercial solar PV technology project in Kano State of Nigeria. Polysun® simulation software was used to locate a suitable location and 1MW solar PV system was design using the software to test the commercial and technical feasibility of deploying commercial solar PV technology project in the location. A high yield of annual global irradiation sum of 2,233.3kWh/m2 and annual sum of the diffuse radiation of 811.2kWh/m2 were recorded from the location. The simulated annual direct current (DC) and alternating current (AC) output of the system were found to be 2, 043,910kWh and 1,847,846.1kWh respectively. The system performance ratio was found to be 73.1%. The project was economically evaluated and levelised cost of electricity (LCOE) generation from the system was calculated to be 37.6Naira/kWh which is lower than the approved renewable energy tariff of 40.25Naira/kWh as approved by the Nigerian Electricity Regulatory Commission for year 2016. The project was technically evaluated to be feasible and economical profitable based on the simulation output data.*
Keywords: *Solar PV technology, LCOE, Renewable energy, Nigeria*

I. INTRODUCTION

The utilization of clean energy resources has become crucial due to the necessity to reduce the greenhouse gases (GHG), responsible for the global warming that represents a threat to our world. Enormous resources and effort has been placed worldwide on researching and developing new green technologies in order to fulfill the increasing global energy demand and avoiding the noxious emissions produced by fossil fuel-based sources of energy generation. The Sun power is one of the most attractive renewable technologies as it can be harnessed by direct and indirect processes and does not represents any hazard to the environment. The energy emanating from the Sun arrives to the Earth as electromagnetic waves in different wavelengths and this radiation is the most extensive source of clean energy that could exist on Earth [1].

Nigeria is the most populous country in Africa with a population of over one hundred and sixty million people with electric power consumption (KWh per capita) of 121.51 in 2009. This low power generation capacity, falls short of national demand, thus resulting in acute power shortage across the country [2]. There are currently 23 grid-connected generating plants in operation in the Nigerian Electricity Supply Industry (NESI) with a total installed capacity of 10,396.0 MW and available capacity of 6,056 MW. Most generation is thermal based, with an installed capacity of 8,457.6 MW (81% of the total) and an available capacity of 4,996 MW (83% of the total). Hydropower from three major plants accounts for 1,938.4 MW of total installed capacity (and an available capacity of 1,060 MW) [3]. Electricity generation in Nigeria continue to experience multiple technical problems as a result of pipeline vandalism activities by militancy activities in the southern part (Niger Delta) region of the country, which remain the main source of gas supply to gas generating plants across the country. The electricity supply falls to an ironic 0MW level in the end of first quarter of 2016 as a result of different technical constraints that continues to hamper the output of the aging electrical generation and transmission facilities in the country.

Nigeria is endowed with vast mix of renewable energy resources as studied by different researchers. The vast potentials of different renewable energy resources across Nigeria have been widely studied by Ohunakin [4], Ajayi [5] and Habib [6] has reported a solar PV potential of 33641.85MWh over an area of 203.89 km2. Cumulative global installed solar photovoltaic (PV) capacity is set to continue its growth from 271.4 Gigawatts (GW) in 2016 to 756.1 GW by 2025, registering a compound annual growth rate (CAGR) of 13.1%, according to research by consulting firm Global Data [7].The rapid deployment of solar PV, working in combination with high learning rates (for every doubling of cumulative installed capacity PV module costs decline by 20-22%) has led to dramatic cost declines in the last 10 years. Crystalline silicon (c-Si) PV module prices have fallen by over 65% over the last two years alone. This is driving reductions in installed costs. Utility-scale solar PV projects can now have lower installed costs than for wind in some markets and have lower installed costs than for coal-fired power stations in virtually all OECD countries to a high of around USD 0.31/kWh depending on the region for utility-scale projects. With solar PV module prices of around USD 0.75/W for crystalline silicon modules, future cost reductions will increasingly be determined by cost reductions in the balance of system (BoS) [8].

One of the world's largest PV markets is Germany with the driving force being the favorable feed-in tariff law on solar electricity. These regulations have enabled consumers to supply additional green (PV) electrical energy to the grid network at prices above that of network electricity. In Nigeria, a similar regulation exists through embedded generation, which can be described as a form of generation where excess renewable energy generated by a consumer above the 1 MW mark may be sold to a nearby distribution network at prices that are higher than grid electricity. This is presented in the multi-year tariff order for 2012-2017. Therefore PV technology can supply a significant amount of electricity, thus making significant contributions to improving the nations' energy deficit [9]. On 21st of July 2016 the government owned power purchasing company; Nigeria Bulk Electricity Trader (NBET) signed a power purchase agreement with a consortium of 12 companies to generate solar PV electricity at a price of 11.5 cents per kWh [10].

This study assessed the technical and economic potential of solar PV technology in Kano State of Nigeria using simulated climate data generated using Polysun® simulation software. The design of 1MW system was undertaken and annual energy output of the system was generated using simulation climate data of the selected location. Levelised cost of electricity generation from the system was economical evaluated to help potential investors explore the feasibility of investing in solar PV technology in the selected location and its associated cost benefits.

Levelised Cost of Electricity generation (LCOE) is the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. An electricity price above this would yield a greater return on capital, while a price below it would yield a lower return on capital, or even a loss. The LCOE of renewable energy technologies varies by technology, country and project, based on the renewable energy resources, capital and operating costs, and the efficiency/performance of the technology. The approach used in this study is based on a simple discounted cash flow (DCF) analysis. This method of calculating the cost of renewable energy technologies is based on discounting financial flows (annual, quarterly or monthly) to a common basis, taking into consideration the time value of money. Given the capital intensive nature of most renewable power generation technologies and the fact that fuel costs are low, or often zero, the weighted average cost of capital (WACC), also referred to as the discount rate in this study, used to evaluate the project has a critical impact on the LCOE. The formula used for calculating the LCOE of renewable energy technologies is [11]:

$$\mathbf{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad \ldots\ldots\ldots\ldots \quad (1)$$

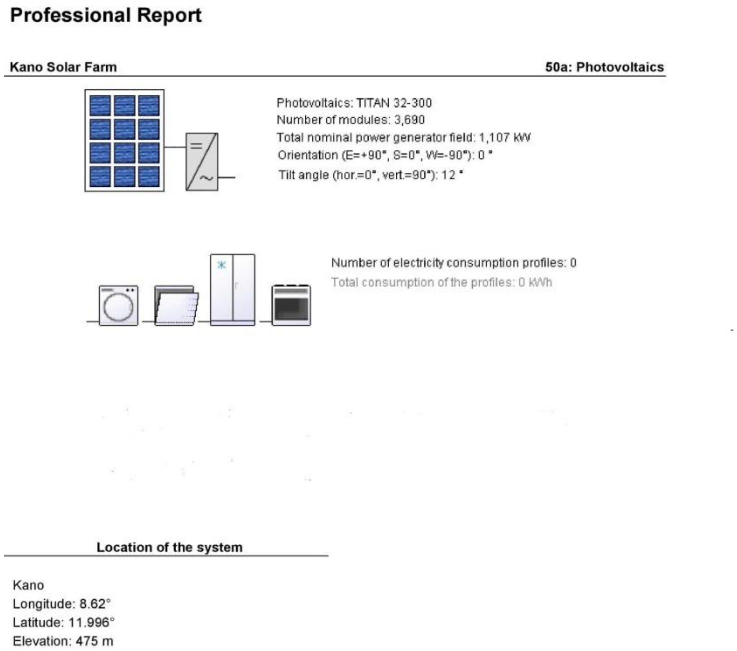
LCOE = the average lifetime levelised cost of electricity generation
$\mathbf{I_t}$ = investment expenditure in year t
$\mathbf{M_t}$ = operations and maintenance expenditures in the year t
$\mathbf{F_t}$ = Fuel expenditures in the year t
$\mathbf{E_t}$ = electricity generation in the year t
r = discount rate; and n = economic life of the system

II. MATERIALS AND METHODS

2.1 System Design

The solar PV technology power system used in this research work was designed using Polysun® simulation software. The company Vela Solaris of Switzerland develops and distributes the simulation software Polysun. Polysun® software offers valuable support with the design, analysis and calculation of installations in the field of renewable energies [11]. A grid connected system was designed with power capacity of 1107kW. Technical data associated with this designed are given in Figure 1 and 2.

Figure 1: Technical Design Parameters of the system (Source: [11])



2.2 Design Scope

The scope of this study is limited to the design of solar PV power system with capacity of 1107kW located at Kano city in the northwestern region of Nigeria. The system is grid connected to a local distribution line and electricity generated is assumed to be sold to the local distribution company, Kano Electricity Distribution Company (KEDCO), at the approved tariff of 11.5 cents per kWh. The simulation software was used to simulate the location climate data with TITAN32-300 solar PV module as shown in figure 2.

Figure 2: Solar PV system plan and associated infrastructure (Source: [11])

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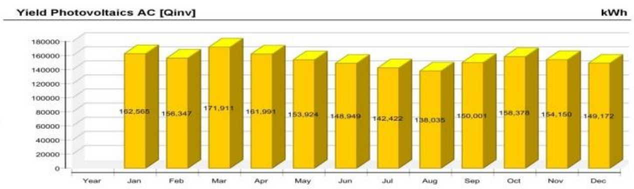
Photovoltaics Roof plan	TITAN 32-300	
Manufacturer		Titan Energy Systems Ltd.
Data Source		Photon
Number of modules		3,690
Number of modules (layout)		3,690
Total nominal power generator field	kW	1,107
Total gross area	m²	6,420.07
Tilt angle (hor.=0°, vert.=90°)	°	12
Orientation (E=+90°, S=0°, W=-90°)	°	0
Inverter 1: Name		SG1260TS
Inverter 1: Manufacturer		Sungrow Power Supply Co., Ltd.
Inverter 1: Number of phases		3
Layout 1: Number of inverters		1
Layout 1: cos phi		1
Layout 1: A number of strings		369
Layout 1: A modules per string		10
Total nominal power of all inverters	kVA	1,000
Energy production DC [Qpvf]	kWh	2,043,910
Energy production AC [Qinv]	kWh	1,847,846
Specific annual yield	kWh/kWp/a	1,669.2
Reactive energy [Qinvr]	kvarh	0
Apparent energy [Qinva]	kVAh	1,847,846
Derating losses [Qder]	kWh	0



Yield Photovoltaics DC [Qpvf]

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh	204391	179641	172708	189951	179111	170364	164885	157799	152986	165929	175167	170418	164952

III. Results and discussions

3.1 System Location

The system is located at Kano city in the northwestern region of Nigeria, Longitude 8.62°, Latitude 11.996° and elevation of 475m. The project total gross area was simulated to be $6{,}420.1m^2$.

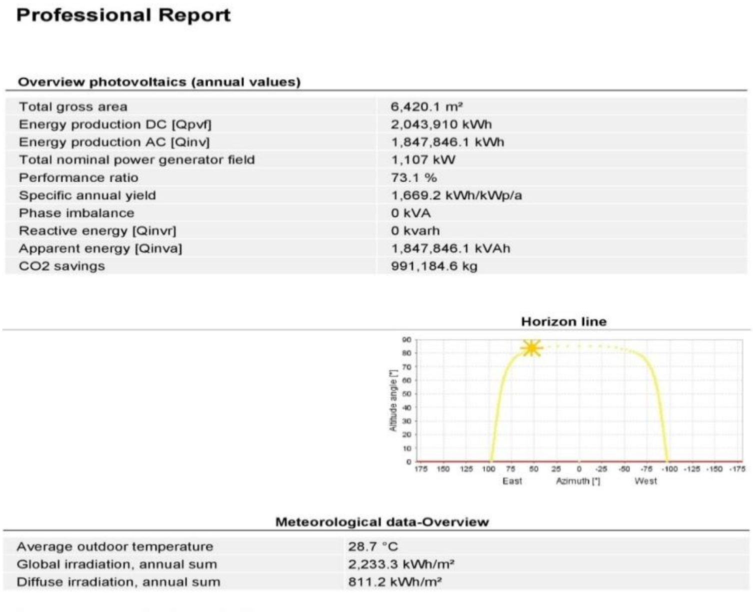
3.2 Meteorological Data

The simulated meteorological data from the location was based on the meteonorm global satellite temperature and radiation data. Average annual temperature of the location was found to be 28.7°C, Annual global irradiation sum was found to be 2,233.3kWh/m^2 and annual sum of the diffuse radiation was found to be 811.2kWh/m^2.

3.3 Annual Energy Output

The simulated annual direct current (DC) and alternating current (AC) output of the system were found to be 2, 043,910kWh and 1,847,846.1kWh respectively. The system performance ratio was found to be 73.1%.

Figure 3: Solar PV system Energy annual output (Source: [11])



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Overview photovoltaics (annual values)

Total gross area	6,420.1 m²
Energy production DC [Qpvf]	2,043,910 kWh
Energy production AC [Qinv]	1,847,846.1 kWh
Total nominal power generator field	1,107 kW
Performance ratio	73.1 %
Specific annual yield	1,669.2 kWh/kWp/a
Phase imbalance	0 kVA
Reactive energy [Qinvr]	0 kvarh
Apparent energy [Qinva]	1,847,846.1 kVAh
CO2 savings	991,184.6 kg

Meteorological data-Overview

Average outdoor temperature	28.7 °C
Global irradiation, annual sum	2,233.3 kWh/m²
Diffuse irradiation, annual sum	811.2 kWh/m²

3.4 Levelised Cost of Electricity generation

The following assumptions were considered based on the Nigerian Electricity Regulatory Commission (NERC) regulations on feed-n tariff for renewable energy sourced electricity in Nigeria template for base year 2016 in evaluating the levelised cost of electricity generated using the system design in this study[12]:

Table 1: Assumptions for renewable energy feed in tariff computation (Source: [12])

Project Type	Solar PV	
Capacity	MW	5
Capital Cost	$/kW	1500
Fixed O&M	$/kW/year	30.00
Variable Cost	$/MWh	0.06
Fuel Cost	$/MWh	0
Real WACC	%	11
Feed in Tariff for Base year 2016	$/kWh	0.115
Exchange rate Naira to Dollar (N to $)	***N to $***	350

The levelised cost of electricity generated using system design in this study was calculated over generation period of 10 years and the resulting output is given in Table 2

Table 2: Simulation assumptions for renewable energy feed in tariff computation (Source: [11])

Project Type	Solar PV		1 Year	10 Years
Capacity	kW	1,107		
Capital Cost	$/kW	1,660,500		
Electricity Generation	kWh		1,847, 846.1	18,543,700
Fixed O&M	$/kW/year	30.00	11,623,500	116,235,000
Variable Cost	$/MWh	0.06	38,941.77	389,417.70
Fuel Cost	$/MWh	0	0	0
Real WACC	%	11	11	11
Exchange rate Naira to Dollar (N to $)	***N to $***	350	350	350
Feed in Tariff for Base year 2016	$/kWh	0.115	0.115	0.115

Using the formula in equation (1) the levelised cost parameters in the Naira equivalent
LCOE = the average lifetime levelised cost of electricity generation in 10 years
I_t = N581, 175, 000
M_t = Fixed and Variable **O&M** for 10 years = **N116, 235,000 + N389, 417.70 = N 116, 624, 417.70**
F_t = N 0
E_t = sum electricity generation in 10 years = **18,543,700 kWh**
r = discount rate = **11%**
n = **10 years**

The LCOE = $$\frac{\sum_{t=10}^{n}\frac{581{,}175{,}000+116{,}624{,}417.70+0}{(1+0.11)^{10}}}{\sum_{t=10}^{n}\frac{18{,}543{,}700}{(1+0.11)^{10}}}$$

=37,629.99 N/MWh
=37.62999 N/kWh

3.5 Discussion of Results

Energy output simulated using Polysun® shows monthly energy output from the chosen location in Figure 2. Highest monthly generation was recorded in March with a value of 171,911kWh and lowest generation was recorded in August with a value of 138,035kWh.The Solar PV system specific annual yield was recorded to be 1,669.2kWh/kWp/a and system performance ratio of 73.1%. A sum of 991,184.6Kg of CO_2 is recorded as avoided amount of CO_2 emission to the atmosphere if the system is used to generated electricity. The levelised cost of electricity generated using the system in this study was calculated to be 37.63 Naira/kWh based on the estimates of installed capital cost of 1500$/kW as adopted by Nigerian Electricity Regulatory Commission (NERC) [12]. The value of LCOE calculated for the solar PV system used in this study is below the approved tariff of 11.5 cents/kWh (40.25Naira/kWh; adopting exchange rate of Naira to dollar to be 350) and this shows that investment in Solar PV project in the selected location used in this study is feasibly profitable and technically sound considering the high yield annual global irradiation sum of 2,233.3kWh/m^2 and annual sum of the diffuse radiation of 811.2kWh/m^2 recorded from the location.

IV. CONCLUSION

The results of this research study have demonstrated a significant finding for prospect of commercial solar PV in the selected location used. The output of the technical and commercial analysis from the selected location can be used to consider preliminary analysis of commercial solar PV technology projects and policy making. Further detail ground measurements of the location climate data and more detail financial analysis will be needed to make informed decision for commercial investment and policy making

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