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Solar Energy Potentials of Some Selected Locations in Northeastern Nigeria

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Sunlight is the primary source of clean and cheap energy but its intensity varies from one location to another depending on the latitude, altitude, atmospheric absorption and scattering by air molecules, dust particle and water vapour among others. The aim of this work is to determine the solar energy potentials of Gombe (latitude 10° 16' 59.9988'' N and longitude of 11° 10' 0.0012'' E), Jalingo (latitude 8° 53' 34.2672'' N and Longitude 11° 22' 37.74'' E), Damaturu (Latitude 11° 44' 49.1856'' N and Longitude 11° 57' 58.2912'' E) and Bauchi (latitude 10° 18' 50.9724'' N and longitude 9° 50' 46.6152'' E) in northeastern Nigeria, the process involves obtaining the solar irradiation data for these four locations from a renewable energy simulation package (photovoltaic geographical information system, PVGIS) for a period of 10 years, a daily, monthly and annual solar irradiation was obtained for each of these locations. A peak monthly values was obtained in the month of January for Gombe, Jalingo and Bauchi while the month of March has the peak value for Damaturu, an average daily solar irradiation of 5.8977kWh/m^2/day, 5.9026 kWh/m^2/day, 6.0337 kWh/m^2/day and 5.9821kWh/m^2/day and an annual values of 2154.44kWh/m^2/yr, 2056.17 kWh/m^2/yr**,** 2202.30kWh/m^2/yr and 2150.60kWh/m^2/yr for Gombe, Jalingo, Damaturu and Bauchi respectively. These locations have very similar atmospheric conditions and hence a closer range of solar energy potentials compared to places like Lagos, Onitsha and Sapele in Delta state with (4.42kWh/m^2/day), (4.43kWh/m^2/day, and 5.31 kWh/m^2/day respectively. Damaturu has the highest solar irradiance among the four locations studied. Grid- connected PV system and thermal system (concentration thermal technology) can be built to support electricity generation and hot water production respectively for residential and industrial use. The utilization of Solar oven,

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cookers and coolers technology should be encourage by government and non-governmental organization, this will help stop global warning and desert encouragement and hence conserve other natural resources(such as forest) for other use (furniture construction).

Keywords: Renewable energy; solar energy potentials; solar irradiations; solar energy; sunlight.

1. INTRODUCTION

Solar energy is one of the renewable sources of energy; energy that continues to replenish faster than the rate at which they are utilized, renewable energy are clean, cheap and environmentally friendly [1]. Wind, biomass and hydro-electric energy are other example of renewable energy sources.

The extraterrestrial solar insolation of 1367W/m^2 is constant throughout but atmospheric scattering, absorption and reflection by air molecules, dust particles and water vapour affects the intensity of the incoming sunlight irradiation. The intensity of sunlight energy vary from one location to another, it depends on some factors like latitude, altitude of the locations, climatic factors and atmospheric conditions, all affects the amount of solar energy of any geographical locations [2]. Locations with lower latitude (around the equator 0^o) tends to have higher solar irradiation and higher ambient temperatures than locations with higher latitude; around the north poles and south poles of the globe [3].

Altitude also affects solar energy potentials of a location, location at higher altitude; far above the sea levels, tends to have lower ambient temperature whereas location with lower altitude tends to have higher temperature [4]. Ambient temperature affects the efficiency of a photovoltaic solar panels by a decrease of 0.5% per degree rise in panel temperature [5]. Clouds and other shading by surrounding building, tall trees and telecommunication mask etc. can affect the intensity of solar irradiation at any locations, rainy seasons tends to have lower solar irradiations than dry seasons [6]. Blowing winds also aid in the cooling of solar photovoltaic panels and hence winter months with higher wind speed is more favorable for PV systems thansummer months with lower wind speed [7].

Most locations have variation of these parameters (latitude, altitude, wind speed, atmospheric temperature, humidity and cloud covers) that determine solar energy potentials. Therefore there is a need to ascertain the amount of solar energy potentials for individual location for example Maiduguri has solar irradiations of 6.176 kW/m^2/day [8] , Kano (6.08 kWh/m^2/day), Onitsha (4.43 kWh/m^2/day) in south eastern Nigeria and Lagos (4.42 kWh/m^2/day) in south western Nigeria were evaluated byOkoye et al. [26].

Yola in northeastern Nigeria has between A maximum and minimum of 6.68 kWh/m^2/day (in April) and 4.98 kWh/m^2/day (in August) [9]. Jos has between 7 kWh/m2/day and 6.7 kWh/m^2/day for the month of January [10] while Abuja has maximum value of 6.27 kWh/m^2/day and minimum value of 4.19 kWh/m^2/day in the months of March and August respectively [11].

The best way to obtain solar irradiation data are through an in-situ with high quality measurement sensors, with repeated measurement and sensors continuously been calibrated regularly and to generate a data over long period of time preferably 10 years or more. This practically not attainable. This why a validated renewable energy simulation package (i.e photovoltaic geographical information system, PVGIS) come handy [12,13].

The purpose of this work is to determine the solar energy potentials of Gombe, Jalingo, Damaturu and Bauchi and in the process obtain the daily, monthly and annual solar irradiation data for these four locations in northeastern Nigeria. Renewable energy sources like solar has environmental and health benefits, it provide cheap, clean and environmentally friendly energy, a good sources of electricity for remote use in agriculture and for rural settlements: street lighting, sources of water for farm animals and irrigation, egg incubation in poultry farming, electrical fending and vaccine refrigeration among others.

2. THEORETICAL BACKGROUND

2.1 Sunlight Energy

Sunlight is the primary source of energy on the earth, the sun utilizes nuclear process to generate enormous amount of energy, several million tons of mass of atom is converted to energy in a nuclear fusion reaction in the sun, where hydrogen atoms are converted to helium atoms [15]. About 1.08×10^8 GW of energy from the sun reaches the earth on a day bases which is about 8000 times of the energy needed on the earth for industrial, commercial and residential use [15]. Therefore the energy of the sun is sufficient for global energy requirement. The energy of the sun comes in two form; visible light spectrum and infrared (heat) spectrum. The visible part of the solar spectrum can be converted to electricity using photovoltaic principle where sunlight energy is converted directly into electrical energy. The infrared part is converted into heat energy using solar thermal collectors.

2.2 Variation of Solar Power Output

The amount of solar irradiance incident on surface per unit area called insolation vary from one location to another with latitude, altitude, atmospheric absorption and scattering by air particles and water vapours [2]. Location with lower latitude; closer to the equator tends to have higher solar irradiations than location far away from the Equator, the equatorial region of the globe comparatively have more sunlight hours and average ambient daily temperatures than locations far away from the equator like the tundra in other polar regions of the globe [3].

The amount of sunlight intensity reaching a place depends on the latitudes, altitudes, atmospheric scattering and absorption by water vapour, gaseous particles and dust particles [2]. The thickness of the atmosphere during a time of the day or season of the years affects the sunlight energy potentials at any point. The thicker the atmosphere; the more the presence of water, vapour and dust particles (to scatter and absorb incoming solar rays) the lower the solar irradiance and lighter the atmosphere (absence of water vapour and dust particle) the higher the solar irradiance. Presence of cloud cover, cloud cover will out-rightly block the solar irradiance received and hence months of the wet season tends to have less irradiance than months of the dry season [6].

2.3 Photovoltaic Effects

Photovoltaic system is a process where sunlight energy is converted to electricity directly when a solar panel is exposed to sunlight. A phenomenon where electric voltage or current is generated when solar cell or PV cell are exposed to sunlight. Solar cells do not need fuel to produce electricity or have any mechanical part before they can generate electricity. The amount of electric power that can be generated by a solar panel depends on the incoming solar irradiance and the temperature of the solar panel. The efficiency of a solar panel increases with a decrease in cell temperature by about 0.5% per a degree rise in temperature and degrade also by about 0.5% annually as it ages [25]. The most common types of solar cell are the silicon types but other technologies like cadmium telluride (CdTe), copper indium gallium selenide (CIGS) among others [15]. Photovoltaic system can generate clean, cheap and free energy when harnessed.

2.4 Solar Thermal System

The sunlight energy come inform of heat and light, the heat part can be harnessed and utilized for domestic use. Thermal collector are devices absorb sunlight light energy and convert to heat which can be used for cooking, boiling and drying [16]. Common example of devices using sunlight energy for cooling and heating are solar cookers, solar oven, solar water heaters, solar dryers among others. Solar heating can be used in industries like pharmaceuticals and drug, paper, leather and textiles. A concentrating solar system uses a reflecting surfaces to concentrate the sunlight to a single spot or comparatively small area. These are system that uses larger reflecting mirrors or lenses to concentrate a large area of sunlight into a receiver [17]. Electricity can be generated when the concentrated heat is used to heat a steam turbine connected to electric generator. A concentrating system are far more efficient than flat plate collector, can concentrate temperature to about 200^oC [18] which several times higher than ambient temperature. A good example of concentration solar system are the parabolic through and dish solar water system.

3. MATERIALS AND METHOD

3.1 Materials

1. HP laptop computer.
2. PVGIS CODE.

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3.2 Method

A solar irradiation data is obtained from a renewable energy simulation package, i.e photovoltaic geographical information system, PVGIS-CODE for a period of 10 years from 2007 to 2016. Monthly solar irradiation and annual solar irradiation were obtained for each year from 2007 to 2016. Annual daily average is then obtained by dividing the annual solar irradiation by number of days in a year, leap years are taken into consideration. Mean monthly and annual is then obtained for each of the four locations. The input parameters are the latitude and longitude of the location in decimal forms.

The co-ordinates of Gombe (latitude 10° 16' 59.9988'' N and longitude of 11° 10' 0.0012'' E), Jalingo (latitude 8° 53' 34.2672'' N and Longitude 11° 22' 37.74'' E), Damaturu (Latitude 11° 44' 49.1856'' N and Longitude 11° 57' 58.2912'' E) and Bauchi (latitude 10° 18' 50.9724'' N and longitude 9° 50' 46.6152'' E) are inputted into the PVGIS-CODE interface respectively, a year range of 2007 to 2016(a period of 10 years) is chosen and the simulation process is done.

3.2.1 PVGIS CODE

Photovoltaic geographical information system is a renewable simulation package that can predict the photovoltaic power output of any solar panel in Africa, Europe and Asia. It has two solar radiation database, the surface solar radiation dataset-Heliosat (SARAH) and surface application facility on climate monitoring (CMSAF) database.

3.2.2 Validation of PVGIS-CODE

The PVGIS, photovoltaic geographical information system was accepted by the European Union (EU) for estimation of photovoltaic power output after a vigorous scientific research work. The data obtained in PVGIS is validated with Baseline Surface Radiation Network (BSRN) measurements, BSRN is a ground based station that accurately record solar radiation data over different cities in the globe. A validation data from 10 different ground based stations are showing the absolute mean bias difference MBD (W/m^2) and the root mean square difference (RMSD, W/m^2) for the selected ground stations in the Table 1 below [19,20].

3.3 Description of the Study Area

3.3.1 Bauchi

Bauchi is located in northeastern Nigeria, on latitude 10° 18' 50.9724'' N and longitude 9° 50' 46.6152'' E, has an elevation of 616 m above sea level.. Bauchi has two season, the wet and dry season, the wet season lasting for about 4.6 months starting the 16th of May o the 3rd October and a dry season lasting for about 7.4 months starting from 3rd October to 16th of May. Bauchi has an annual average temperature of 57°F to 100°F and is rarely below 51°F or above 104°F [21].

3.3.2 Gombe

Gombe is located in northeastern Nigeria, on latitude 10° 16' 59.9988'' N and longitude of 11° 10' 0.0012'' E, has an elevation of 461 m above the sea level. Gombe has two seasons, rainy and dry season, the rainy season lasts *4.5 months*, starts from May 22 *to* October 6*,* and the dry season lasts *7.5 months*, starts from *October 6* to *May 22*. Gombe has an annual average temperature ranging from *57°F* to *100°F* and is rarely below 52°F *or above* 105°F [22].

Table 1. A Photovoltaic Geographical Information System (PVGIS) Validation Data

S/No.	Station	Latitude	Longitude	MBD (W/m^2)	RMSD (W/m^2)	Year0 - YearN
1	Cabauw (NL)	51.9711	4.9267	1.3	86.9	2005-2020
2	Camborne (UK)	50.2167	-5.3167	-1.6	74.3	2005-2017
3	Carpentras (FR)	44.083	5.059	6.7	56.5	2005-2018
4	Cener (SP)	42.816	-1.601	7	85.2	2009-2020
5	De Aar (SA)	-30.6667	23.993	3.3	79.6	2005-2020
6	Eastern North Atlantic (PT)	39.0911	-28.0292	2	65.8	2015-2015
7	Florianopolis (BR)	-27.6047	-48.5227	4.3	112.2	2013-2020
8	Gobabeb (NA)	-23.5614	15.042	3.3	60.8	2012-2020
9	Lindenberg (DE)	52.21	14.122	2.2	70	2005-2018
10	Payerne (SW)	46.815	6.944	0.7	72.4	2005-2020

3.3.3 Jalingo

Jalingo is located in northeastern Nigeria, on latitude 8° 53' 34.2672" N and Longitude 11° 22' 37.74" E, has an elevation of 220 m above the sea level. Jalingo has two seasons, the wet and dry seasons, the wet seasons starts last for *6.1 months*, starts from *April 18* to *October 21 and the dry season* lasts *5.9 months*, from October 21 *to* April 18*.* Jalingo has an has an annual average temperature ranging from *61°F* to *99°F* and is rarely below 56°F or above 105°F [23].

3.3.4 Damaturu

Damaturu is located in northeastern Nigeria, on latitude 11° 44' 49.1856" N and Longitude 11° 57' 58.2912" E, has an elevation of 371m above season level. Has two season, the wet seasons and dry season, the wet season lasts 3.9 months, starting from June 3 *to* September 30 while the drier season lasts 8.1 months, from September 30 to June 3. The temperature typically varies from 58°F to 104°F and is rarely below 52°F or above 109°F [24].

4. RESULTS AND DISCUSSION

4.1 Results

The monthly solar irradiation data for a period of 10 years (2007-2016) as well as the daily average and annual values for Gombe (latitude 10° 16' 59.9988" N and longitude of 11° 10' 0.0012" E), Jalingo (latitude 8° 53' 34.2672" N and Longitude 11° 22' 37.74" E) , Damaturu (Lattitude 11° 44' 49.1856" N and Longitude 11° 57' 58.2912" E) and Bauchi (latitude 10° 18' 50.9724" N and longitude 9° 50' 46.6152" E) are obtained and presented in Table 2, 3, 4 and 5 respectively. The daily average as well as the annual values are also obtained.

Table 2. Estimation of Monthly Solar Irradiation Data For Gombe From 2007 To 2016

Months| Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean Monthly
January	205.6	198.7	205.2	208.3	211.1	211.7	200.2	201.8	206.8	211.3	206.066
February	182.2	204.5	192.6	195.7	174.2	199.5	197.2	193.6	193.2	207.5	194.023
March	215.1	208.6	205	204.8	215.7	213.7	207	190	202.3	194.5	205.674
April	178.3	170.5	166.6	181.9	183.2	193.6	177.2	183.2	206.2	197	183.777
May	161.5	173.4	166.3	165.1	173.7	172.8	175.2	167.6	184.6	176.3	171.638
June	157	151.4	153.3	153.1	156	164.5	154.6	165.4	157.8	163.3	157.643
July	139.8	149.2	150	135.3	155.4	148	158	149.9	161.4	147.5	149.44
August	124.3	132.9	142.4	133.8	123.4	142.9	126.5	138.8	154.1	146.3	136.527
September	161.9	160.4	170.8	151.4	154.6	167.6	167.4	156.7	152.6	168.5	161.187
October	195	200	169.9	180	173.5	185	190.6	189.3	188.7	198.2	187.009
November	186.4	197.9	192.1	194.7	203.2	194	197.2	199.5	198.9	201.4	196.527
December	204.3	207.5	207.5	206.6	210	208.4	204	203.3	198.1	199.7	204.933
Annual	2111.3	2154.8	2121.8	2110.8	2133.9	2201.6	2155	2139.1	2204.6	2211.6	2154.444
Daily	5.7844	5.8875	5.8133	5.7831	5.8463	6.0152	5.904	5.8605	6.0399	6.0425	5.902586301

Table 3. Estimation of Monthly Solar Irradiation Data For Jalingo From 2007 To 2016

Month/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean Monthly
January	213	205.6	209	213.9	216.9	215.6	207.6	206.1	219.3	217	212.392
February	188.2	210	192.9	200.8	170.8	193.7	197.8	196.7	190.9	210	195.165
March	209.5	202.1	200.7	204.7	217.4	218.3	206.2	191.5	189.1	184.5	202.389
April	174.7	167.3	161.1	183.5	176.1	183.8	174.5	182	203.3	183.7	178.987
May	164.1	166.4	162	152.6	150.8	164.5	171.3	159.1	170.1	158.8	161.978
June	131.6	131.2	143.5	142.7	141.5	148.1	145.8	147.8	132.2	142.2	140.661
July	125	133.4	136.5	116.5	132.9	124.2	125	116.6	134.1	134.5	127.867
August	112.7	119.2	124.6	118	114.5	117.8	100.7	108.8	126.3	127.3	116.986
September	144.5	137.6	151.5	125.3	122.3	139.4	151.1	139.9	135.2	153.7	140.05
October	170.8	189.2	158.6	155.1	167.9	172.7	176	173.5	168.8	181.2	171.378
November	191.2	202.8	190.2	191.6	207.6	198.9	200.2	192.9	198.6	203	197.695
December	212.2	213.9	215	213.5	215.2	213.4	203.5	211.4	202	206.1	210.626
Annual	2037	2079	2046	2018	2034	2090	2060	2026	2070	2102	2056.174
Daily	5.582	5.679	5.604	5.529	5.572	5.711	5.643	5.552	5.671	5.743	5.63335342

Table 4. Estimation of Monthly Solar Irradiation Data For Damaturu From 2007 To 2016

Month/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean Monthly
January	205.87	197.06	203.77	209.77	209.25	212.57	200.8	199.73	206.7	211.97	205.749
February	190.01	205.13	197.65	196.71	177.29	204.49	198.2	197.92	194.46	209.11	197.097
March	219.22	218.89	218.36	213.57	222.15	223.16	209.1	192.7	208.96	200.92	212.703
April	178.66	187.42	180.49	188.54	192.04	195.56	187.6	187.47	210.02	192.39	190.019
May	175.75	176.07	174.94	182.84	181.36	175.51	180.1	170.22	187.33	178.48	178.26
June	156.48	154.75	156.04	161.13	162.26	160.85	162.8	169.94	168.32	158.77	161.134
July	151.31	149.59	154.71	130.65	166.61	151.85	159.6	152.24	159.33	153.97	152.986
August	131.76	140.15	148.89	142.66	141.11	151.37	141.2	153.53	161.05	153.14	146.486
September	168.15	164.41	177.08	155.72	158.38	178.3	169.4	162.61	168.51	175.34	167.79
October	199.41	204.38	169.91	183.28	182.01	189.14	197.7	191.81	196.45	202.95	191.704
November	187.99	203.88	189.26	193.24	204.2	197.46	196.6	193.6	199.14	198.17	196.354
December	200.92	205.54	204.53	203.95	207.44	206.27	198.9	200.68	197.45	194.53	202.021
Annual	2165.5	2207.3	2175.6	2162.1	2204.1	2246.5	2202	2172.5	2257.7	2229.7	2202.303
Daily	5.933	6.0308	5.9606	5.9235	6.03863	6.1381	6.0329	5.9519	6.1855	6.0922	6.03370685

Table 5. Estimation of Monthly Solar Irradiation Data For Bauchi From 2007 To 2016

Month/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean Monthly
January	205.77	196.01	203.99	210.49	210.62	212.97	200.9	204.76	210.76	214.85	207.112
February	189.12	205.38	195.82	197.91	179.69	203	197	193.79	193.79	210.51	196.6008
March	212.71	213.59	209.25	206.25	215.22	217.24	205.2	191.18	206.42	192.67	206.973
April	173.1	171.02	169.03	183.54	186.57	187.63	177.1	181.33	207.57	194.46	183.135
May	161.92	169.03	171.07	162.58	166.58	170.85	173.8	166.23	176.93	171.5	169.049
June	159.43	152.05	146.28	153.91	151.98	157.83	149.9	165.82	151.74	160.05	154.899
July	159.43	141.54	146.13	131.24	151.09	146.78	150.4	145.28	154	138.15	146.404
August	140.37	131.79	149.08	142	128.6	147.51	128.1	132.03	141.39	142.37	138.324
September	129.58	158.37	160.53	155.87	151.79	157.83	166.5	161.9	152.15	160.78	155.53
October	167.58	199.53	164.22	173.19	183.4	186.77	185.1	194.25	188.5	203.86	184.64
November	188.91	202.83	193.18	194.33	205.67	195.96	204	198.71	197.68	202.46	198.373
December	206.3	208.06	208.93	204.4	211.08	210.47	204.3	204.94	202.52	197.62	205.862
Annual	2094.2	2149.2	2117.5	2115.7	2142.3	2194.8	2142.3	2140.2	2183.5	2189.3	2146.9018
Daily	5.7376	5.8721	5.8014	5.7965	5.8693	5.9968	5.8693	5.8636	5.9821	5.9816	5.877032164

4.2 Discussion

The average daily solar irradiance of Gombe, Jalingo, Damaturu and Bauchi is 5.8977 kWh/m^2/day, 5.9026 kWh/m^2/day, 6.0337 kWh/m^2/day and 5.9821 kWh/m^2/day respectively. The annual solar irradiance is 2154.44 kWh/m^2/yr, 2056.17 kWh/m^2/yr**,** 2202.30 kWh/m^2/yr and 2150.60 kWh/m^2/yr for Gombe, Jalingo, Damaturu and Bauchi respectively. Gombe, Jalingo and Bauchi has the month of January with highest solar irradiance while Damaturu has the month of March with the highest solar irradiance. The month of August has the least solar irradiance for all the four locations. Damaturu has the highest solar irradiance followed by Bauchi, Jalingo and least by Gombe.

4.2.1 Solar Energy Potentials of Gombe

The solar energy potentials of Gombe is 5.8977 kWh/m^2/day and an annual values of 2154.44 kWh/m^2/yr for Gombe on latitude 10° 16' 59.9988'' N and longitude of 11° 10' 0.0012'' E. Gombe has an average maximum monthly solar irradiation of 206.066 kWh/m2 in the month of January and minimum average in the month August with a value of 136.527 kWh/m^2. Gombe has a solar irradiation of 206.066 kWh/m2, 194.023 kWh/m^2, 205.674 kWh/m^2, 183.777 kWh/m^2, 171.638 kWh/m^2, 157.643 kWh/m^2, 149.44 kWh/m^2, 136.527 kWh/m^2, 161.187 kWh/m^2, 196.527 kWh/m2, and 204.933 kWh/m^2 for the months of January, February, March, April, May, June, July, August, September, October, November and December respectively. The 10 year data from 2007 to 2016 and mean monthly data as presented in Table 1.

4.2.2 Solar Energy Potentials of Jalingo

The solar energy potentials of Jalingo (latitude 8° 53' 34.2672'' N and Longitude:11° 22' 37.74'' E) 5.9026 kWh/m^2/day and an annual value of 2056.17 kWh/m^2/yr with a peak monthly value in the month of 212.39 kWh/m^2 in the month of January and lowest value of 116.99 kWh/m^2 in the month of August. Jalingo in Taraba state has a monthly solar irradiation value of 212.39 kWh/m^2 195.167 kWh/m^2, 202.39 kWh/m^2, 178.99 kWh/m^2, 161.98 kWh/m^2, 140.66 kWh/m^2, 127.867 kWh/m^2, 116.986 kWh/m^2, 140.05 kWh/m^2 kWh/m^2, 171.38 kWh/m^2, 197.70 kWh/m^2 and 210.63 kWh/m^2 for the months for the months of January, February, March, April, May, June, July, August, September, October, November and December respectively. The 10 year data from 2007 to 2016 and mean monthly data as presented in Table 2.

4.2.3 Solar Energy Potentials of Damaturu

The solar energy potentials of Damaturu (Latittude 11° 44' 49.1856'' N and Longitude 11° 57' 58.2912'' E) 6.0337 kWh/m^2/day and an annual value of 2202.30kWh/m^2/yr with a peak monthly value of 212.70kWh/m^2 in the month of March and lowest value of 146.48kWh/m^2 in the month of August. Jalingo in yobe state has a monthly solar irradiation value of 205.748 kWh/m^2, 197.099 kWh/m^2, 212.704 kWh/m^2, 190.017 kWh/m^2, 178.259 kWh/m^2, 161.138 kWh/m^2, 152.985 kWh/m^2, 146.482 kWh/m^2, 167.794 kWh/m^2, 191.703 kWh/m^2, 196.356 kWh/m^2 and 202.018 kWh/m^2.for the months of January, February, March, April, May, June, July, August, September, October, November and December respectively. The 10 year data from 2007 to 2016 and mean monthly data as presented in Table 3.

4.2.4 Solar Energy Potentials of Bauchi

The solar energy potentials of Bauchi (latitude 10° 18' 50.9724'' N and longitude 9° 50' 46.6152'' E) 5.9821kWh/m^2/day and an annual value of 2150.60kWh/m^2/yr with a peak monthly value of 207.05kWh/m^2 in the month of January and lowest value of 137.24kWh/m^2 in the month of August. Bauchi in Bauchi state has a monthly solar irradiation value of 207.05 kWh/m^2, 196.87 kWh/m^2, 207.01 kWh/m^2, 183.14 kWh/m^2, 169.05 kWh/m^2, 154.90 kWh/m^2, 144.50 kWh/m^2, 137.24 kWh/m^2, 159.33 kWh/m^2, 187.27 kWh/m^2, 198.37 kWh/m^2 and 205.86 kWh/m^2 for the months of January, February, March, April, May, June, July, August, September, October, November and December respectively. The 10 year data from 2007 to 2016 and mean monthly data as presented in Table 4.

The location with the highest solar irradiance among the four locations we have studied is Damaturu town in Yobe state, a photovoltaic PV system can be built to support the electricity energy production in the state in the form of grid-connected PV system and PV system farm can be built to support electricity generation in the north eastern region by the federal government of Nigeria.

5. CONCLUSION

The solar energy potentials of Gombe is 5.8977kWh/m^2/day, Jalingo has solar energy potentials of 5.9026 kWh/m^2/day, Damaturu has 6.0337 kWh/m^2/day while Bauchi has 5.9821 kWh/m^2/day. These lies within the range of 3.5 kWh/m^2/day to 7.0 kWh/m^2/day for coastal areas and far northern Nigeria [28]. These four locations in northeastern Nigeria has very similar atmospheric conditions and hence a closer range of solar energy potentials compared to places like Lagos, Onitcha and Sapele in Delta state with (4.42 kWh/m^2/day), (4.43kWh/m^2/day, [26]) and 5.31 kWh/m^2/day (Ohorhoro *et. al.,* 2016) respectively. Maiduguri in same northeastern Nigeria has 6.176 kWh/m^2/day [27].

Damaturu has the highest solar energy potential, a solar energy station can be built to support the electricity load in the state the whole of the northeastern region. Solar energy technology like solar cooking, solar water heating and refrigeration can support fight against desert encouragement, greenhouse emission and general global warming. Renewable energy sources like solar can be harnessed for the generation of cheap, clean and environmentally friendly energy using photovoltaic cells to generate electricity or for solar cooking and heating using thermal heat collectors and concentrating solar collectors. Photovoltaic system can be used remotely in street lighting, electrical fencing for crops and animals, provision of water for drinking by farm animals and irrigations.

6. RECOMMENDATION

An off grid PV system can be built to support residential electricity load by household in all of the four location because the solar energy potentials is within the good range for optimum PV power output.

In addition, thermal PV system can be built to support hot water production by industries or industries using the concentration PV technology to generate hot water for residential and industrial use. The utilization of Solar oven, cookers and coolers technology should be encourage by government and non-governmental organization, this will help stop global warning and desert encouragement and conserve other natural resources(such as forest) for other use (furniture construction).

Subsequent research should focus on wind energy potentials as an alternate source of renewable energy, government and tertiary institution should built a ground base solar energy measurement stations because it rarely available in northeastern Nigeria. These will provide both short and long time data and will ease constraints for research into renewable energy studies such time, resources and personnel.

LIMITATIONS

This research work rely on satellite based data and not an in-situ data due to constraints of time, resource and personnel. PVGIS solar irradiation data have very low absolute mean bias difference MBD (W/m^2) of 2.92 when compare with many ground based solar irradiation stations and this made it highly accurate. Satellite data are more reliable (not accurate) than many in-situ because only with a high quality measurement sensors, repeated measurements at least every hour, having Sensors calibrated regularly and generating data for a long time period, preferably 10 years or more, with only will in-situ data be better than satellite simulation data.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Shaikh MR, Shaikh S, Waghmare S, Labade S, Tekale A. A Review Paper on Electricity Generation from Solar Energy. International Journal for Research in Applied Science and Engineering Technology. 2017;887. DOI:10.22214/ijraset.2017.9272.
2. Rathod A, Mittal P, Kumar B. Analysis of factors affecting the solar radiation received by any region. 2016;1-4. DOI:10.1109/ETCT.2016.7882980.
3. Chiang C, Olsen JE, Basler D, Bånkestad D, Hoch G. Latitude and Weather Influences on Sun Light Quality and the

Relationship to Tree Growth, Forests. 2019;10:610.
DOI:10.3390/f10080610

4. Panjwani MK, Narejo DB. Effect of Altitude on the Efficiency of Solar Panel. International Journal Of Engineering Research and General Science. 2014;2.
5. Revati D, Natarajan E. Enhancing the Efficiency of Solar Cell by Air Cooling. Indian Journal of Science and Technology. 2016;9.
DOI:10.17485/ijst/2016/v9i5/87274.
6. Kasaeian A, Feidt Ml, Petrescu S, Mellit A. Solar Thermal Engineering. International Journal of Photoenergy. 2017;1-2.
DOI:10.1155/2017/7493781.
7. Sarkar MNI. Estimation of solar radiation from cloud cover data of Bangladesh Renewables. 2016;3:11.
Available:https://doi.org/10.1186/s40807-016-0031-7
8. Muhammad AB, Shodiya S, Ngala G. Feasibility study of solar-wind hybrid power system for Maiduguri area of Nigeria; 2015.
DOI:10.13140/RG.2.2.18472.11525.
9. Muzaffar A, Muhammad HI, Nadeem AhS, Hafiz MA, Manzoor MS, Muhammad M, Khan, K, Fikri T. "Performance Investigation of Air Velocity Effects on PV Modules under Controlled Conditions. International Journal of Photoenergy. 2017;10.
Article ID 3829671,
Available:https://doi.org/10.1155/2017/3829671
10. Esbond GI, Funmilayo SWO. Solar Energy Potential in Yola, Adamawa State, Nigeria. Department of Mathematical Sciences, University of Maiduguri Borno State, Nigeria; 2020.
11. Ayegba A, Tochukwu MW. Investigation of Global Solar Energy Potential of Jos, Plateau State, Nigeria, International Journal of Trend in Research and Development. 2017;4(2).
ISSN: 2394-9333
Available:www.ijtrd.com
12. Osueke CO, Uzendu P, Ogbonna ID. Study and Evaluation of Solar Energy Variation in Nigeria, International Journal of Emerging Technology and Advanced Engineering. 2013;3(6).
Available:www.ijetae.com
ISSN 2250-2459, ISO 9001:2008 Certified Journal
13. Huld T, Müller R, Gambardella A. A new solar radiation database for estimating PV performance in Europe and Africa. *Solar Energy*. 2012;*86*(6):1803-1815.
14. Huld T, Šúri M, Dunlop ED. A GIS Based System for Performance Assessment of Solar Energy Systems over Large Geographical Regions,‖ Solar 2006 Conference: Renewable Energy, key to climate recovery, 7-13 July 2006, Denver CO,USA; 2006.
15. Orhorhoro EK, Orhorhoro OW, Ikpe A. Study of solar energy potential in Sapele, Nigeria. Int. J. of Thermal & Environmental Engineering. 2016;13(2):129-133.
16. Kasaeian A, Feidt Ml, Petrescu S, Mellit A. Solar Thermal Engineering. International Journal of Photoenergy. 2017;1-2.
DOI:10.1155/2017/7493781.
17. Blanco MJ, Santigosa LR. Advances in concentrating solar thermal Research and Technology; 2016.
18. Maio D, Alessandro C, Luca D, Musto M, Gennaro E, Rotondo Giuseppe RR. Thermal Efficiency of a Concentrating Solar Collector Under High-Vacuum. Journal of Physics: Conference Series. 1599. 012029.
DOI:10.1088/1742-6596/1599/1/012029.
19. PVGIS data sources & calculation methods.
Available:https://joint-research-centre.ec.europa.eu/pvgis-photovoltaic-geographical-information-system/getting-started-pvgis/pvgis-data-sources-calculation-methods_en
(Accessed on 10/03/2022)
20. PVGIS. Photovoltaic geographical information system.
Available:https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP
21. Weathersparks Climate in Bauchi
Available:https://weatherspark.com/y/61868/Average-Weather-in-Bauchi-Nigeria-Year-Round
(accessed on 23/02/2022)
22. Weathersparks Climate in Damaturu
Available:https://weatherspark.com/y/68827/Average-Weather-in-Damaturu-Nigeria-Year-Round (accessed on 23/02/2022)
23. Weathersparks Climate in Gombe
Available:https://weatherspark.com/y/68815/Average-Weather-in-Gombe-Nigeria-Year-Round
(accessed on 23/02/2022)
24. Weathersparks Climate in Jalingo

Available:https://weatherspark.com/y/68797/Average-Weather-in-Jalingo-Nigeria-Year-Round
(accessed on 23/02/2022)
25. Jordan DC, Kurtz SR. Photovoltaic Degradation Rates—an Analytical Review. Progress in Photovoltaics: Research and Applications. 2013;21.
DOI:10.1002/pip.1182.
26. Okoye, C., Taylan O, Baker DK. Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design. Renewable and Sustainable Energy Reviews. 2016;55:550–566.
DOI:10.1016/j.rser.2015.10.154
27. Muhammad AB, Shodiya S, Ngala GM. Feasibility Study of Solar-Wind Hybrid power System for Maiduguri Area of Nigeria. In University of Maiduguri Faculty of Engineering Seminar Series. 2015;6.
28. Lloeje OC. Potentials for Renewable Energy Application in Nigeria Energy Commission of Nigeria. 1997;5-16.

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