Solar Energy Potential in Yola, Adamawa State, Nigeria

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Abstract: - The energy characteristics of the monthly solar radiation data from Yola, a town in Northeastern Nigeria, is examined. A preliminary descriptive analysis show that the data are negatively skewed. Five distributions were fitted to the data and the Weibull distribution provided the best fit for each of the months of the year. The energy output for a standard residential (1.626 m^2) panel with 18.7% efficiency and a standard commercial (1.935 m^2) panel with 23% efficiency, when exposed to solar radiation, are computed for each month using the Weibull distribution. The minimum radiation value was recorded in August. This gives a realizable energy output of 1.514 kWh and 2.216 kWh for standard residential and commercial panels, respectively. These energy outputs are equivalent to lighting 25.2 and 35.4 60-watts lightbulbs, respectively. For a solar cell farm of 1000 standard commercial panels, the realizable energy output is 2.2 MWh. Consequently, there is a good prospect for solar electricity generation in Yola.

Key-words: - *Weibull distribution, solar energy, generalized log-likelihood ratio test, electricity generation*

1 Introduction

Climate change and its resultant consequences has caused a paradigm shift in energy production and consumption; cars and electrical equipments that use renewable energy are in use. The popular use of fossil fuels is gradually being replaced by renewable energy sources such as geothermal, hydro, wind, solar, tidal, biomass, among many others. These energy sources are non-depletable, pollution-free, side-dependent and self-replenishable. They are almost cost-free, except for the cost of the technology used in harnessing them.

Solar and wind power are the fastest growing energy sources among the large number of renewable energy sources. Solar power, in particular, is the second largest most deployed renewable energy technology in terms of global installed capacity after wind [6]. Solar photovoltaic technologies are more easier to deploy and give direct power for household and commercial uses with the aide of converters and storage batteries.

Nigeria depends largely on fossil fuel for electricity generation whereas there is abundance of sunshine, particularly in the northern part of the country. A study of solar radiation in Nigeria is useful as it can provide the drive for the realization of a clean source of electricity generation.

2 The Problem

Yola, the Adamawa State capital in northesatern Nigeria, is located in the midland climatic zone on the grid coordinates of latitude 9.23°N and longitude 12.47°E, with an altitude of 186.05 m above sea level [13]. Electricity supply to Yola and environs, like many other places in Nigeria, is not sufficient to meet the yearning needs for domestic and industrial uses. Some businesses and households do resort to petrol and diesel powered generators, contributing to global warming. Aside, the high cost of fuel, this makes business difficult to run.

Solar photovoltaic cells could come in handy since its deployment only requires converters and storage batteries. Although many resources have been channeled by governments and well-spirited persons to provide street lights and water pumping systems using solar photovoltaic cells, most of these installations hardly last a full year. This, to a large extend, is due to inadquate knowledge of the solar power capacity of the area for appropriate design and deployment of photovoltaic cells. Understanding the solar power potentials of an area also depend on the understanding of the random nature of solar radiation. The purpose of this study is to find among the extreme value distributions, that which will best accommadate the random nature of the solar radiation data from Yola, with a view to estimate the solar energy that is realizable from the sun in the area.

3 Literature Review

Power generated by photovoltaic cells is growing globally, with installed capacity of 135 GW by the end of 2013 [9]. There has been an exponential growth in the installation of solar photovoltaic cells; the 2016 estimate of cumulative installed capacity stood at 306 GW and the projection for 2018 ending is 500 GW, with expected installations to reach 104 GW in the year [11].

Regression models, such as the Angstrom model, have been used to describe the characteristics of the solar power potentials of certain areas in Nigeria. Specifically, a regression [14] model was constructed based on the Angstrom model to determine the global solar radiation of Bida, Niger State, using sunshine hour duration, relative humidity, rainfall, wind speed, minimum and maximum temperatures as independent variables. Global solar irradiance was also expressed in terms of location latitude, daily relative sunshine, daily maximum temperature, daily average relative humidity and cosine of the hour angle for 12 locations in Nigeria [1].

Probability models have been used for the study of some renewable energy sources. For instance, the Weibull distribution was found to be the best model for describing the wind speed data generation process of Maiduguri, among many other distributions [7,8]; also the gamma distribution with shape and scale parameters as functions of month-hourly mean value and maximum value, respectively, of the clearness index was used in the analysis of weather data for energy assessment in a hybrid solar-wind power system [16]. Several distributions were fitted to the solar radiation data of Ibadan with the logistic distribution found to best describe the data [3]; here, statistical properties of root-mean-square-error (RMSE), mean-absolute-error (MAE), mean-absolute-percentage-error (MAPE) and coeeficient of determination were used to detemine the best fit. Different probability distributions were found to fit the solar radiation data for different months and seasons of the year [2, 15].

4 Data

Daily record of the Gunn Bellani solar radiometer were obtained from the Nigerian Meteorological Agency (NiMET) office at the Yola Airport for the year 2015. The data, in millimeters, were converted into MJ/m^2/day using the conversion factor of 1.216 [12]. They were further converted into kWh/m^2/day using another conversion factor of 0.28. A box and whisker plots of the converted daily solar radiation for each month of the year are given in Fig. 1 in the Appendix.

5 Methodology

5.1 Preliminary Investigation

The box and whisker plots are used for a preliminary investigation of the distribution of the solar energy data of Yola. The plots are examined for skewness, symmetry and existence of outliers in the data. The plots for each month of the year are presented in Fig. 1. And from the figure, the plots indicate a negatively skewed distribution since the median values are greater than the mean for all the months of the year except August. Also, the dots give indications of outlying observations for some months of the year.

5.2 Fitting Distributions

The skewness detected in Fig. 1 informed the choice of fitting the Weibull, extreme value (EV), generalized extreme value (GEV), lognormal and gamma distributions to the solar energy data from Yola in order to determine the best fitted model. The probability density functions of these distributions are given below.

The Weibull density function is given by

$$f_X(x) = \frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta-1} exp\left(-\left(\frac{x}{\alpha}\right)^{\beta}\right) \qquad (1)$$

$$x > 0, \alpha > 0, \beta > 0$$

The extreme value (EV) density function is given by

$$f_X(x) = \frac{1}{\beta} exp\left(-\frac{x-\mu}{\beta}\right) exp\left(-exp\left(-\frac{x-\mu}{\beta}\right)\right) \quad (2)$$

$x > 0, \mu \geq 0, \beta > 0$

The generalized extreme value (GEV) density function is given by

$$f_X(x) = \frac{1}{\beta}\left(1 + \alpha\frac{x-\mu}{\beta}\right)^{-1-\frac{1}{\alpha}} exp\left(-\left(1 + \alpha\frac{x-\mu}{\beta}\right)^{-\frac{1}{\alpha}}\right) \quad (3)$$

$x > 0, \alpha \neq 0, \mu \geq 0, \beta > 0$

The lognormal density function is given by

$$f_X(x) = \frac{1}{x\beta\sqrt{2\pi}} exp\left(-\left(\frac{\ln x-\mu}{\beta\sqrt{2}}\right)^2\right) \quad (4)$$
$$x > 0, \mu \geq 0, \beta > 0$$

The gamma density function is given by

$$f_X(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma_{(\alpha)}} exp\left(-\frac{x}{\beta}\right) \quad (5)$$

$$x > 0, \alpha > 0, \beta > 0$$

The estimation of parameters of the density functions are carried out using the **fitdistrplus** package in R statistical programming language. Parameter estimates and their standard errors are given in Table 5 in the Appendix. The Kolmogorov-Smirnov goodness-of-fit test statistic is used to test the fit of each density function to the data. This is given by

$$D = \max_{x_{(i)}} \left|F_o\left(x_{(i)}\right) - F_n\left(x_{(i)}\right)\right| \quad (6)$$

The value of the log-likelihood function (LL) is used to determine the best model in each month. These estimates are also presented in Table 6. The distribution with maximum LL value is adjudged the best model in each month. The density histograms and curves of the distributions are presented in Fig. 2 in the Appendix.

5.3 Discussion

From Table 5, the Weibull and generalized extreme value distributions are the best models to describe the solar energy data generation process in all the months considered. The Weibull distribution is identified as best in eight months while the generalized extreme value distribution is best in four. The goodness-of-fit results shows quite clearly that only the Weibull distribution records a good fit in each of the twelve months; all other distributions were rejected in some of the months. The Weibull parameter estimates have small standard errors, which means they are reliable estimates.

It is therefore reasonable to investigate whether a pooled Weibull distribution suffices for each month of the year. This is done using the generalized log-likelihood ratio test [10] with hypotheses stated below

H_0 : The Weibull distribution with the same parameters is tenable over all the months of the year,

H_1 : The Weibull distribution assume distinct parameters in each month of the year.

The asymptotic form of the generalized likelihood ratio test statistic is given by

$$K = -2\log\lambda \quad (7)$$

where K has a chi-square distribution with r degrees of freedom (number of parameters specified by H_0), in this case $r = 2$ and

$$\lambda = \frac{sup_{H_0} L(\theta,\ x_1, x_2, \ldots,\ x_n)}{sup_{H_0 \cup H_1} L(\Omega,\ x_1, x_2, \ldots,\ x_n)}, \quad (8)$$

$\theta \in \Omega$, the parameter space.

The parameter estimates and the log-likelihood value under H_0 are given in Table 5, along with the results of the hypotheses test; while those under the alternative hypothesis, H_1, are obtained from Table 5.

Table 1 Generalized Log-Likelihood Ratio Test Results

$\hat{\alpha}$	$\hat{\beta}$	LL	K	$\chi^2_{2,0.05}$	Remark
6.36	6.72	−590.34	148.47	5.99	Reject H_0

The result of the hypotheses test indicates that the null hypothesis is not compatible with the data. That is, the data suggest that the Weibull distribution should assume distinct parameters in each month of the year.

6 Energy Estimation

6.1 Extractable Energy Estimation

Consequent upon the generalized likelihood ratio test results, the fitted Weibull distribution for each month are used to determine the extractable solar energy from the Yola data using the relation given below

$$E_s = \begin{cases} \alpha g_1, & Webull\ distribution \\ \mu + \frac{\beta(h_1-1)}{\alpha}, & GEV\ distribution \end{cases} \quad (9)$$

where $g_k = \Gamma_{\left(1+\frac{k}{\beta}\right)}$, $h_k = \Gamma_{(1-k\alpha)}$ and E_s is the extractable solar energy

The standard errors for the estimated energy are also computed using the relation

$$se(E_s) = \begin{cases} \frac{\alpha}{n}\sqrt{g_2 - g_1}, & Webull\ distribution \\ \frac{\beta}{n\alpha}\sqrt{h_2 - h_1}, & GEV\ distribution \end{cases} \quad (10)$$

where n is the sample size
These estimates are given in Table 2.

Table 2 Extractable Energy from Solar Radiation Data in Yola

Month	Energy, E_s (kWh/m²/day)	$se(E_s)$
Jan	5.93	.030
Feb	6.57	.021
Mar	6.22	.028
Apr	6.68	.032
May	6.29	.036
Jun	6.04	.032
Jul	5.12	.049
Aug	4.98	.039
Sep	5.06	.056
Oct	6.01	.032
Nov	6.47	.021
Dec	5.65	.031

The values exhibit monthly variation as expected. The peak month is April with expected extractable energy of 6.68 kWh/m^2/day, while August records the lowest average value of 4.98 kWh/m^2/day. These estimates are also subjected to daily variations as can be seen from their respective ranges in the box and whisker plots of Fig. 1.

6.2 Realizable Energy Output

The term photovoltaic refers to the phenomenon involving the conversion of sunlight into electrical energy via a solar cell. The amount of electricity a solar panel produces depends on three important factors: the size of the panel, the efficiency of the solar cells inside, and the angle of contact of the solar radiation with the solar panel [4,5]. Most solar panel installers target the contact angle around 90°, the angle with the most intense contact.

Solar efficiency relates to the amount of available energy from the sun that are converted into electricity. As of 2018, the efficiency of most advanced (commercial) solar cells is closer to 23%, while average solar cells for residential use are around 18.7% efficient [17]. Solar panel efficiency is used in computing the realizable energy output from the extractable energy from solar radiation in Yola. The solar efficiency is computed for two scenarios: (i) one metre squared solar panel and standard solar panel for residential use (5.41 ft. by 3.25 ft. or 1.626 m^2) and (ii) one metre squared and standard solar panel for commercial use (6.41 ft. by 3.25 ft., or 1.935 m^2).

Two tables are presented: efficiency for commercial solar panels (23% conversion rate) and efficiency for residential panels (18.7% conversion rate).

Table 3 Energy Output (kWh) from a Commercial Solar Panel exposed to Solar Radiation in Yola

Month	Panel Size	
	1 m²	Standard (1.935m²)
Jan	1.364	2.638
Feb	1.511	2.924
Mar	1.431	2.768
Apr	1.536	2.973
May	1.447	2.799
Jun	1.389	2.688
Jul	1.177	2.279
Aug	1.145	2.216
Sep	1.164	2.252
Oct	1.382	2.675
Nov	1.488	2.879
Dec	1.300	2.528

Table 4 Energy Output (kWh) from a Residential Solar Panel exposed to Solar Radiation in Yola

Month	Panel Size	
	1 m²	Standard (1.626m²)
Jan	1.109	1.803
Feb	1.228	1.997
Mar	1.163	1.891
Apr	1.249	2.031
May	1.176	1.912
Jun	1.129	1.836
Jul	0.957	1.557
Aug	0.931	1.514
Sep	0.946	1.538
Oct	1.124	1.827
Nov	1.210	1.967
Dec	1.057	1.718

Tables 3 and 4 are represented in Fig. 3

Fig. 3 gives a clear indication of the solar energy potential in Yola. For the least average extractable energy in August, the solar efficiency for a standard commercial panel gives 2.216 kWh output, which is equivalent to giving light to 35.4 60-watts lightbulbs. While the efficiency for standard solar panel for residential use gives a corresponding output of 1.514 kWh, equivalent to lighting 25.2 60-watts lightbulbs.

Hence, a solar cell farm with 1000 standard commercial panels will make 2.2 MWh of electricity available for the national grid. These figures provide a convincing evidence that there is a huge potential for solar energy in Yola.

7 Conclusion

Weibull distribution is shown to be the best fitted model for solar radiation data from Yola. The values computed for the extractable energy for each month range between 4.98 kWh/m^2/day (in August) and 6.68 kWh/m^2/day (in April). This gives an indication that there is a potential for solar energy in Yola. The computed standard panel efficiencies for advanced solar cells (2.216 kWh) and solar cells for residential use (1.514 kWh) provided further empirical evidence that this potential is real.

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Appendix

Table 5 Parameter Estimates, Goodness-of-Fit Test and Best Model for each of the Months

Month	Dist	Prameter Estimates (Standard Errors)			Goodness of Fit Test			LL	Best Model
		α	β	μ	K S	C V	Rem		
Jan	Wei	6.30(.136)	8.69(1.325)		.152	.238	GF	−38.5	GEV
	EV		.978(.126)	5.45(.187)	.189	.238	GF	−45.6	
	GEV	-.732(.128)	.998(.168)	5.81(.192)	.098	.238	GF	−35.8	
	Lnor		.166(.021)	1.77(.030)	.191	.238	GF	−43.1	
	Gam	6.51(1.66)	38.6(9.77)		.184	.238	GF	−42.3	
Feb	Wei	6.83(.101)	13.5(2.01)		.076	.250	GF	−23.9	Weibull
	EV		.583(.082)	6.27(.119)	.123	.250	GF	−27.6	
	GEV	-.504(,133)	.631(.101)	6.42(.130)	.065	.250	GF	−23.3	
	Lnor		.091(.012)	1.88(.017)	.110	.250	GF	−25.2	
	Gam	18.7(5.01)	123(32.8)		.106	.250	GF	−25.0	
Mar	Wei	6.58(.128)	9.64(1.45)		.124	.238	GF	−37.1	GEV
	EV		1.10(.132)	5.73(.211)	.218	.238	GF	−47.8	
	GEV	-.684(.115)	.958(.152)	6.09(.184)	.106	.238	GF	−35.3	
	Lnor		.163(.021)	1.82(.029)	.215	.238	GF	−44.0	
	Gam	6.67(1.70)	41.5(10.5)		.205	.238	GF	−42.7	
Apr	Wei	7.07(.139)	9.58(1.50)		.151	.242	GF	−39.5	GEV
	EV		1.37(.167)	6.08(.268)	.250	.242	Nf	−52.7	
	GEV	-.720(.112)	1.09(.176)	6.55(.213)	.129	.242	GF	−37.2	
	Lnor		.191(.025)	1.88(.035)	.232	.242	GF	−49.5	
	Gam	4.68(1.21)	31.3(8.03)		.215	.242	GF	−47.6	
May	Wei	6.74(.187)	6.67(1.08)		.197	.238	GF	−50.4	Weibull
	EV		1.71(.209)	5.48(.328)	.285	.238	Nf	−61.7	
	Lnor		.286(.036)	1.80(.051)	.301	.238	Nf	−60.9	
	Gam	2.37(.605)	14.8(3.72)		.286	.238	Nf	−58.3	
Jun	Wei	6.43(.162)	7.52(1.16)		.172	.242	GF	−42.9	Weibull
	EV		1.45(.176)	5.38(.283)	.271	.242	Nf	−54.4	
	Lnor		.237(.031)	1.77(.043)	.275	.242	Nf	−52.6	
	Gam	3.50(.907)	21.0(5.39)		.259	.242	Nf	−50.2	
Jul	Wei	5.67(.281)	3.78(.572)		.125	.238	GF	−58.4	Weibull
	EV		1.75(.224)	4.27(.335)	.154	.238	GF	−63.5	
	Lnor		.414(.053)	1.56(074)	.177	.238	GF	−65.1	
	Gam	1.43(.367)	7.31(1.81)		.145	.238	GF	−62.3	
Aug	Wei	5.44(.703)	4.77(.214)		.091	.238	GF	−50.5	Weibull
	EV		1.43(.173)	4.34(.273)	.154	.238	GF	−56.3	
	Lnor		.322(.041)	1.56(.058)	.136	.238	GF	−57.2	
	Gam	2.37(.607)	11.8(2.96)		.109	.238	GF	−54.6	
Sep	Wei	5,64(.321)	3.34(.531)		.152	.242	GF	−59.8	Weibull
	EV		1.90(.252)	4.11(.369)	.189	.242	GF	−64.3	
	Lnor		.476(.061)	1.53(.087)	.207	.242	GF	−66.2	
	Gam	1.11(.291)	5.60(1.41)		.186	.242	GF	−63.5	
Oct	Wei	6.42(.171)	7.04(1.09)		.188	.238	GF	−45.5	Weibull
	EV		1.23(.158)	5.37(.235)	.195	.238	GF	−52.6	
	Lnor		.212(.027)	1.77(.038)	.199	.238	GF	−50.7	
	Gam	4.05(1.03)	24.2(6.11)		.199	.238	GF	−49.6	
Nov	Wei	6.72(.083)	15.3(2.37)		.115	.242	GF	−24.3	GEV
	EV		.969(.111)	6.08(.189)	.266	.242	Nf	−41.2	
	GEV	-.851(.144)	.675(.120)	6,43(.132)	.091	.242	GF	−20.7	
	Lnor		.120(.015)	1.86(.022)	.211	.242	GF	−34.8	
	Gam	11.8(3.07)	76.9(19.8)		.199	.242	GF	−33.3	
Dec	Wei	6.04(.162)	6.90(1.07)		.136	.238	GF	−45.3	Weibull
	EV		1.51(.178)	4.97(.289)	.242	.238	Nf	−57.2	
	Lnor		.273(.035)	1.70(.049)	.211	.238	GF	−56.4	
	Gam	2.94(.752)	16.6(4.17)		.192	.238	GF	−53.4	

Wei = Weibull, Lnor = Lognormal, Gam = Gamma, GF = Good Fit, Nf = Not fit, K S = Kolmogorov Smirnov, C V = Critical Value, Rem = Remark

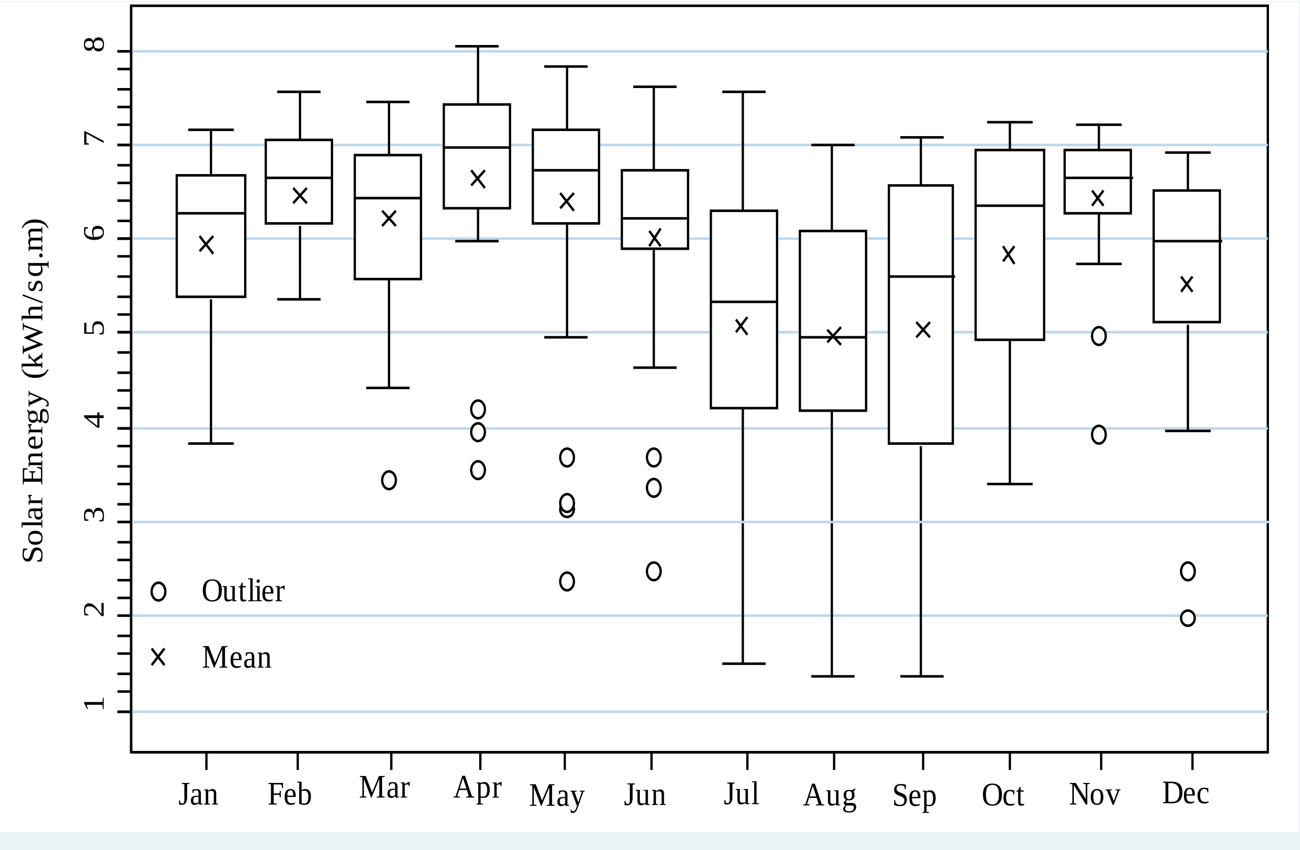

Fig. 1 Box and Whisker Plots of Daily Solar Radiation from Yola

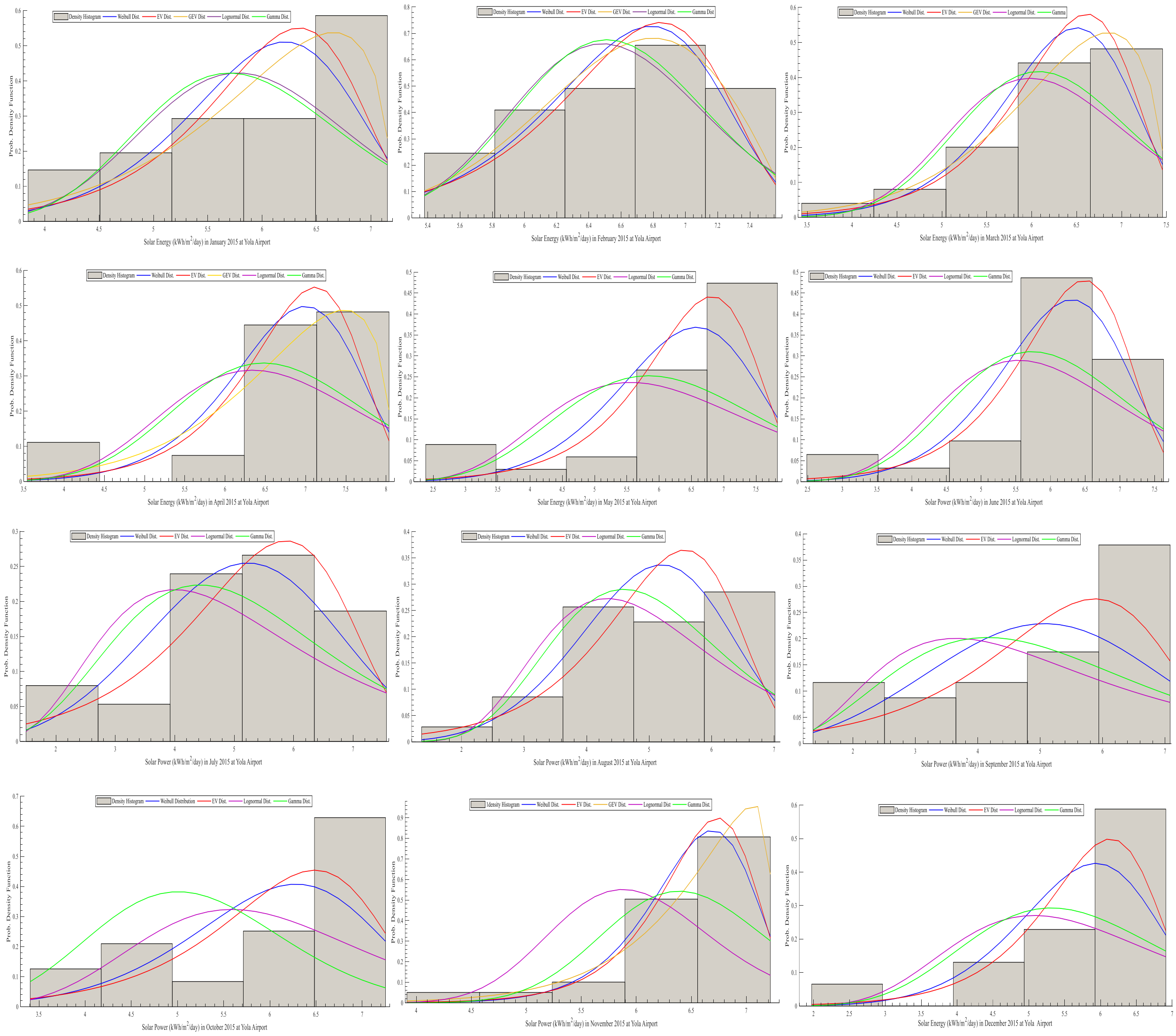

Fig. 2 Density Histograms and Density Curves for the various Distributions

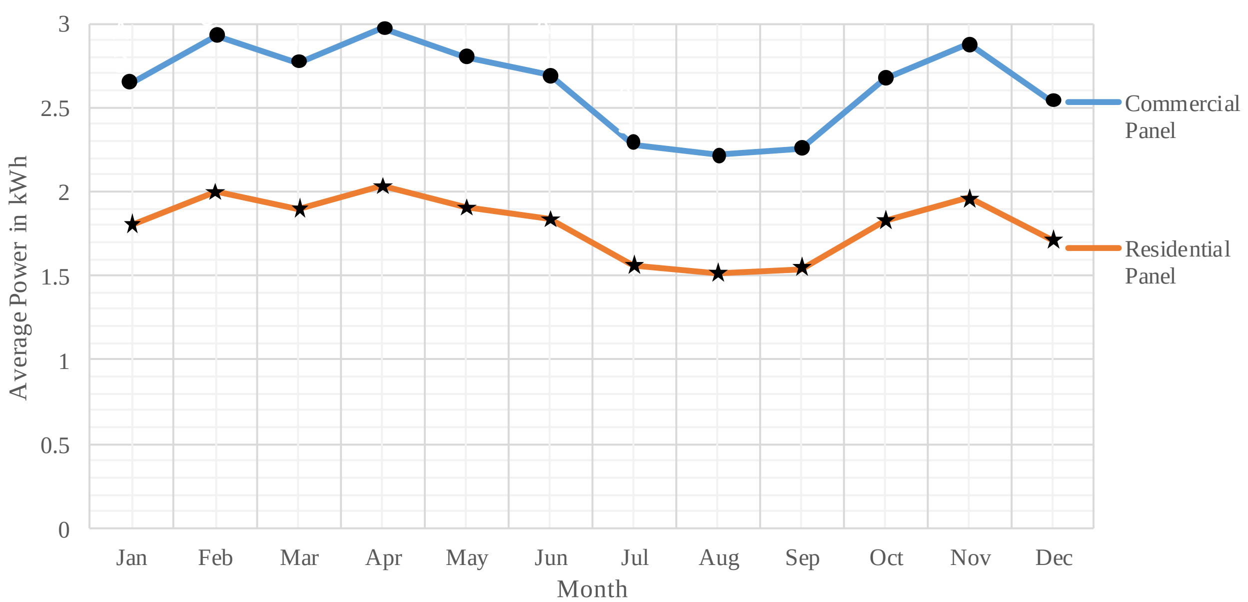

Fig. 3 Energy Output of Solar Panels exposed to Solar Radiation from Yola