ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)
Vol. 4, Issue 2 (April - June 2017)
International Journal of Advanced Research in Education & Technology (IJARET)

Quantitative Evaluation of Wind Potential at 10m on seven sites in Togo

[I]TCHODOU Samah Bawong, [II]Dr. P. KANAGAVEL, [III]G. ARIVUKKODI
[I]Design Engineer in Electrical Engineering, Electrification Project Manager at the Directorate General of Energy, Ministry of Mines and Energy of Togo
[II]Additional Director, Information Training and Customized Services, National Institute of Wind Energy (NIWE), Chennai, India.
[III]Assistant Engineer, Wind Resource Assessment & Offshore (WRA&O), National Institute of Wind Energy (NIWE), Chennai, India.

ABSTRACT

The primary sources used for the production of electricity in Togo are mainly the hydroelectric source and petroleum products. To meet its electricity needs, Togo is turning to neighboring countries in the sub region. Energyimportationhad reached in 2015, 85% of its total electricity needs [1].Togo has resolutely embarked on a process of diversifying its electrical energy resources. The Togolese state has set a target to use the wind resource in the production of electric power by 2025, as it has been demonstrated that in Togo a 25.2MW wind power plant can be installed. It will provide about 5-7% of the country's electricity production, thus contributing to the national effort implemented by the Government to supply electricity to the population [2]. The study of wind potential at 10m height agl is made, on seven sites in Togo namely: Aneho_Amedjonoukou (average annual wind speed AAWS=4.42m/s with average wind power density AWPD=62.12W/m² and a probability P=0.54 that wind speeds between 3-5m/s appear on the site) ,Anie_Adeourou (AWS=3.5m/s ; WPD=35.06W/m² ; P=0.55), Kante_Animene-Tie (AWS=4.33m/s ; WPD=60.49W/m² ; P=0.53), Kante_Titira (AWS=4.32m/s ; DWP=60.34W/m² ; P=0.53), Kara_Sondina (AWS=4.02 m/s ; WPD=48.92W/m² ; P=0.58), Niamtougou_Aliande-Kadjala (AWS=4.18m/s ; WPD=54.56W/m² ; P=0.56) and Notse_Vedome (AWS=3.68m/s ; WPD=37.08W/m² ; P=0.57). It shows that the production of electrical energy by small wind turbines is possible. These results made it possible to understand that more than 60.47% of Togolese territory constitutes favorable areas for the installation of micro wind power with average densities of powers between 24.5 – 94W/m².

KEYWORDS
Wind potential, wind power density, Meteorological data.

I. Introduction

The growing problem of global warming, combined with the reduction of fossil fuel sources, has aroused the public authorities to combine their actions through various international meetings.As of 2014, China, United States, Japan, Russia and India were having highest electricity generation capacity in the world. Among the total electricity installed, nonrenewable sources like fossil fuel and nuclear power are contributing 76.3% and renewable energy is contributing 23.7% and from the total renewable energy installed, hydropower alone contributing 16.6%while 3.7%, 2.0%, 1.2%, 0.4% are from Wind, Bio power, solar PV and Geo, CSP and Ocean respectively [3].Faced with this situation, the use ofrenewable energies is an indispensable solution.

Today, Togo set itself the objective to use its potential renewable energies. Regarding the development of wind technology, no wind power project was significantly developed in Togo. This situation is due to the fact that for a very long time Togo is classified as a less windy area. Recent studies in the Lome port area have shown that 25.2MW wind farm can be installed on this area[4].However, there are areas in Togo,whose study on their wind potential show that more than 34226.66 Km², ie, 60.47% of the territory, correspond to Areas where the average annual wind speed at 10m height is between 3.5-5.5m/s. It is clear that in thoseareas the wind potential is considerable, to allow the intensive use of small wind turbine in rural and semi-urban areas.

Our study, which is part of a process to estimate wind potential in Togo, will contribute to the quantitative assessment of wind potential in the country at 10m height abovegroundlevel and more precisely in seven sites in Togo.

The main objective of this study is to prove that it is possible to use wind turbine technology for the production of electrical energy. It will helpto identify seven sites in Togo and evaluate their wind potential quantitatively.

II. Study Area and Methodology

A. Study Area

Togo covers an area of 56 600 km^2 and has the shape of a 600 km long corridor with a base that does not

ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

exceed 60 km of border on the Atlantic. Togo is between latitude 6° and 11° North and longitude 0° and 2° east of the Greenwich meridian. Togo is a country of plains.However it is crossed by a long chain of mountains from the south-west to the north-east and plateaus which alternating. Togo enjoys an inter-tropical climate due to its altitude. As regards to research on energy sources, at present, it is clear that it is devoid of non-renewable and polluting energy resources. However, it has an advantage in terms of renewable energy sources. Togo has large river network, where hydroelectric potential is estimated at 224 MW, which would correspond to an annual potential production estimated at 850 GWh[1]. Togo has significant solar potential varies from 4.4 KWh/m² to 5.5 KWh/m² with an average power density of 700 W/m². The potential of plant and organic biomass is very high due to the high proportion of the agricultural population, and more recently in 2012 the government approved to install a 25.2 MW capacity of wind power plant on 42 km^2 of unfit soil in the Lome port area [2]. Togo has not yet demonstrated its ability to use ocean energy and tidal energy to produce electricity. Energy consumption is increasing year after year, forcing the country to import more than 75% of its electricity consumption in 2010, compared to 85% in 2015[1].

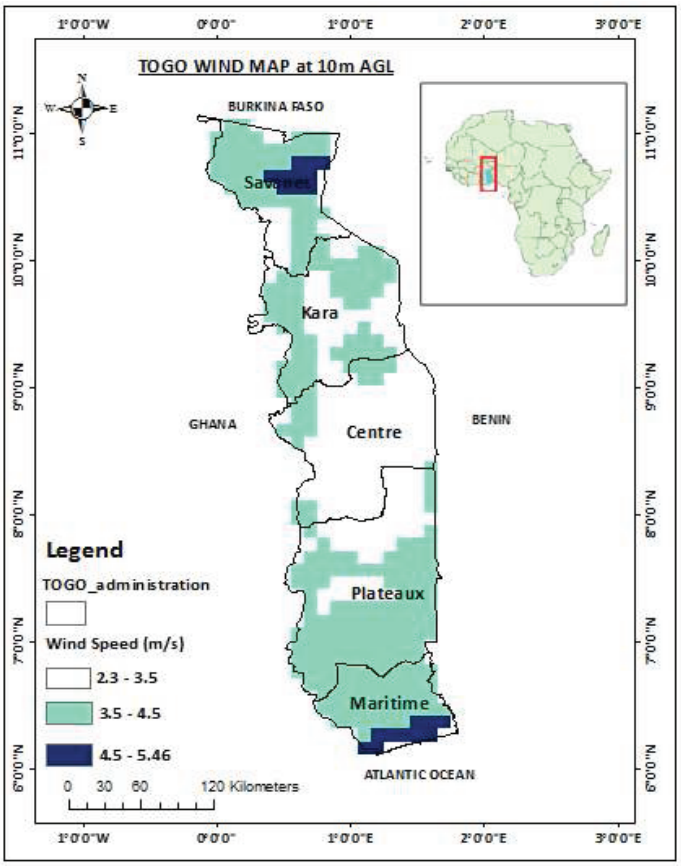

Figure 1.1: Wind map at 10m height above ground level in Togo

B. Wind Potential at 10M ofTogo

Before carrying out the quantative study, identification of sites in Togo is necessary. Togo's wind map at 10m height aglpresented in Figure 1.1 is used. The objective is to quantitatively determine the meteorological data at 10m height agl on the sites as shown in Figure 1.2. Seven sites have been identified namely: Aneho Amedjonoukou,AnieAdeourou, KanteAnimene Tie, KanteTitira, Kara Sondina, NiamtougouAliandeKadjalaand NotseVedome.

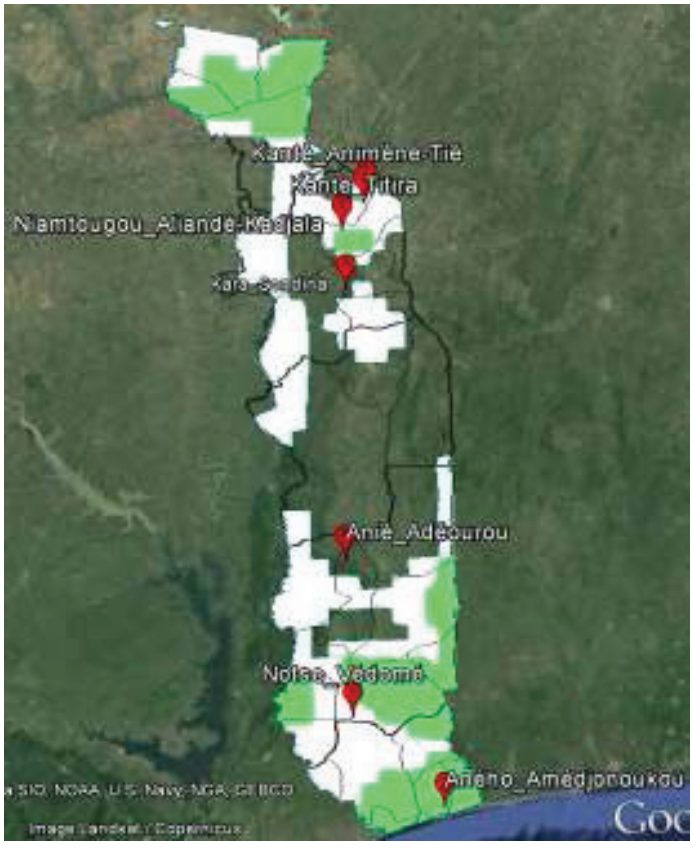

Figure 1.2: Identification of seven study sites in Togo.

C. StudyMethodology

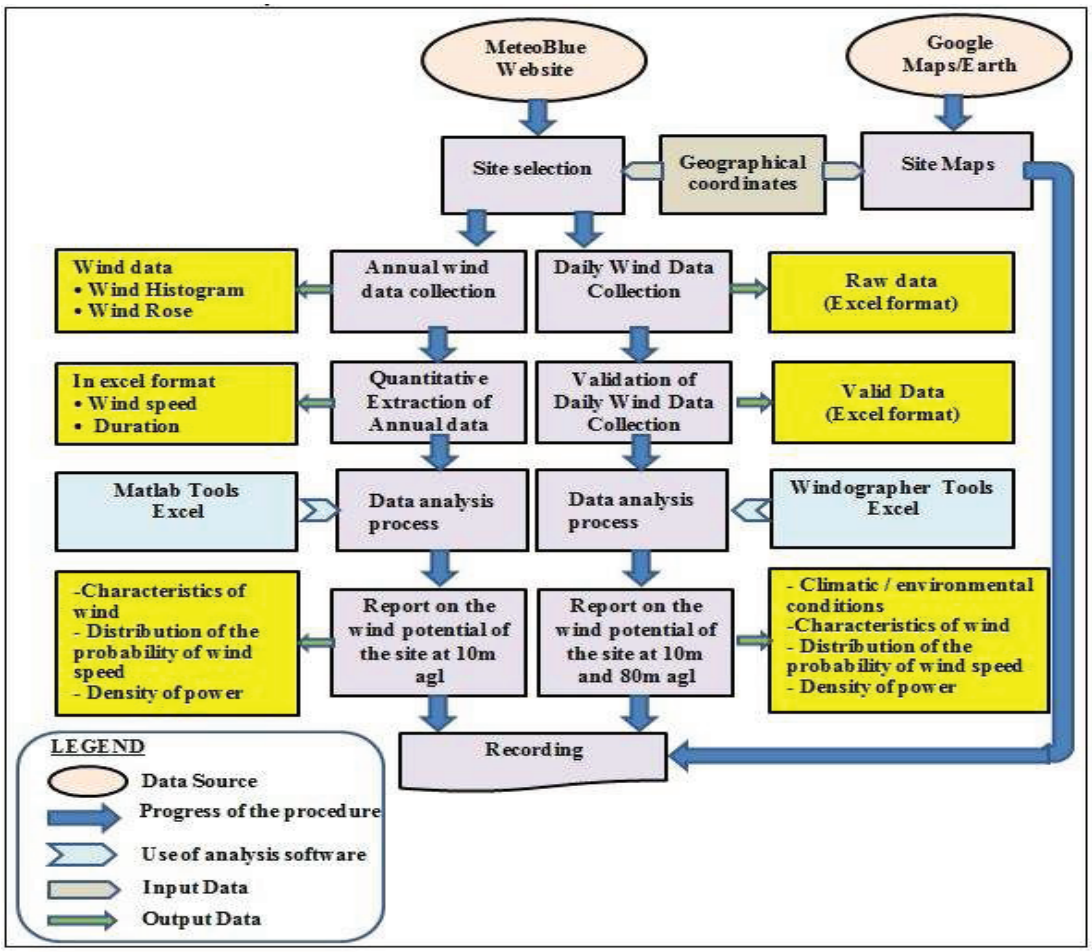

Figure 1.3: Methodology for collecting and analyzing meteorological data

The Methodology consisted of collecting and analyzing meteorological data from the MeteoBlue website [5], and geographic data by using Google Map[6]and Google Earth[7]. Figure 1.3 shows the steps for collecting and analyzing meteorological data.

1. Collection of Meteorological Data

MeteoBlue's website has been accessed in February 2017 and allowed to downloadwind data for the seven sites in Togo. The data collected are of two types: annual and daily data of the wind for the seven sites(covering the period from 23/02/2017 to 25/04/2017). The annual data for each site have been downloaded in the Archive/Climate section. These data are histograms of average daily wind speedsand the Wind Rose for each site. There are a total of seven wind speed histograms and seven wind roses that have allowed to quantitatively extracting information related wind speed and direction.The daily data obtained are hourly data of the wind direction and speed at 10m and at 80m heightagl, in the same moment the pressure and temperature at each site. The data covers the period from 23/02/2017 to 25/04/2017. Analysis of the daily data will enable to gauge the analysis of annual data.

2. Collection of Geographical Data

The geographic data are satellite images obtained from the Google Maps[6]and Google Earth [7] websites. Google Maps is available online.It is used to have two types of views: a classic plan view, with street names, from neighborhood with a resolution of 5m on the ground, and a satellite image with relief, Soil and vegetation with a resolution of 20m on the ground. Google Earth[7]is available and it helpedto determine the elevation of sites above the sea level.

3. Data Analysis

The analysis of data consists of estimating the average wind power density in Togo. The annual

ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

and daily data were analyzed to establish the wind and environmental profile of the different sites.

3.1. Average Wind Power Density

The average wind power density in Togo at 10m height aglwas estimated using the mathematical relationship(1.1).

$$AWPD = \frac{1}{2}\rho\bar{v}^3 \qquad (1.1)$$

Where:
AWPD:is the average wind power density,
ρ : is the average air density (in Togo it is 1.15 Kg/m3),
$\bar{v}$:is the average annual wind speed (in Togo, it is between 2.3-5.46m/s at 10m heightagl).

The results of this analysis are the maps of average wind power density of Togo at 10m height above ground level (agl).

3.2. Annual Data

The analysis of the annual data on the seven sites consisted of extraction of quantitative data on wind from the wind histograms and the wind rose.

- The extraction of data from the wind histogram as shown in Figure 1.4 was done from three situations. For a better explanation of the three situations the example of analysis of the site AnehoAmedjonoukou is presented here.Figure 1.4 shows steps (I), (II) and (III) which allowed extracting the data from the wind speed histograms. The three situations are:

Minimal situation, which has been considered that during the time intervals (I), (II) and (III) those are the winds of low speeds (1.6m/s, 3.4m/s and 5.5m/s) have respectively blew.
Intermediate situation, which has been considered that during the time intervals (I), (II) and (III) those are the velocity winds located in the first quarter of the intervals i.e. 2.05m/s, 3.93m/s and 6.13m/shave respectively blew.
Maximum situation, , which has been considered that during the time intervals (I), (II) and (III) those are the velocity winds located at the center of the intervals i.e. 2.5m/s, 4.45m/s And 6.75m/shave respectively blew.
The Table 1.1 was obtained by this analysis, and gives the quantitative data related to the wind speeds at the site. From this table 1.1, analysis tool of Excel and Matlab software[8]were used for data processing.

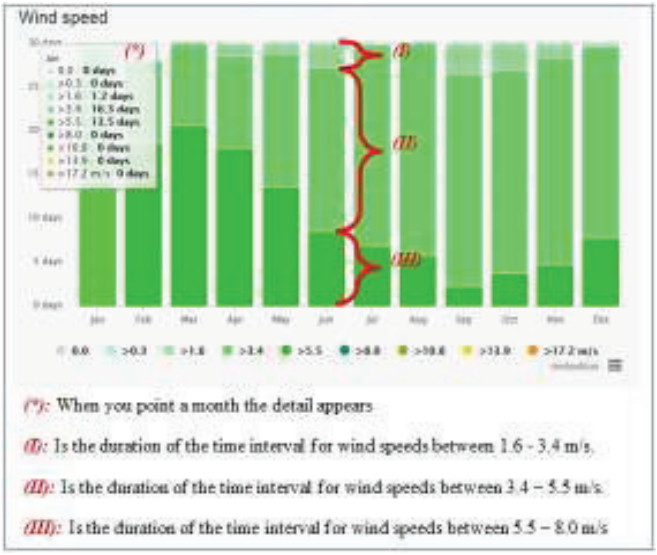

Figure 1.4: Extraction of data from the wind speed histogram

- The extraction of wind rose data was done in all directions as can be seen in Figure 1.5.

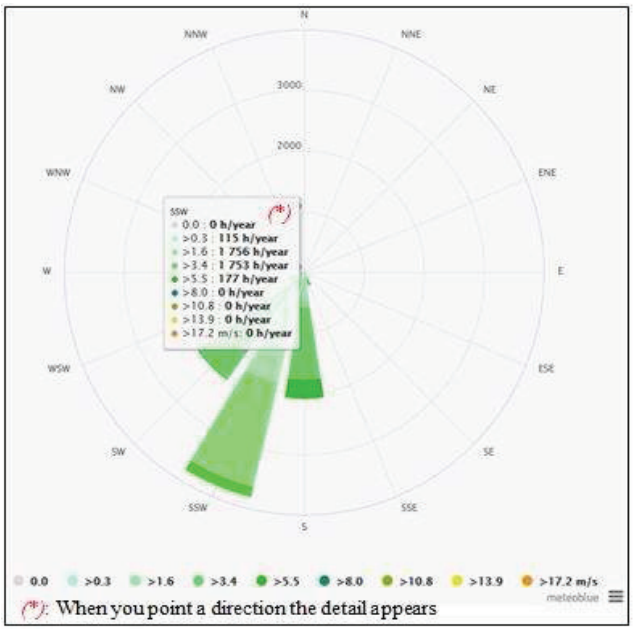

Figure 1.5: Extraction of data from the wind speed histogram

The analysis of wind rose of AnehoAmedjonoukou site is showed as example. Then by pointing a given direction one has the information in number of hours per year related to each wind speed.Table 1.2 is obtained from this analysis obtain, it gives the quantitative data related to the wind directions on the site. From this table 1.2, the predominant wind direction has been determined on the site.

Table 1.1: Wind availability by type of situation

situations	Minimal			Intermediate			Maximal		
Wind Speed m/s	1.6	3.4	5.5	2.05	3.925	6.125	2.5	4.45	6.75
January	28.8	391.2	324	28.8	391.2	324	28.8	391.2	324
February	4.8	223.2	448.8	4.8	223.2	448.8	4.8	223.2	448.8
Marsh	19.2	228	496.8	19.2	228	496.8	19.2	228	496.8
April	33.6	252	434.4	33.6	252	434.4	33.6	252	434.4
May	52.8	362.4	328.8	52.8	362.4	328.8	52.8	362.4	328.8
June	62.4	451.2	206.4	62.4	451.2	206.4	62.4	451.2	206.4
July	28.8	549.6	168	28.8	549.6	168	28.8	549.6	168
August	19.2	583.2	141.6	19.2	583.2	141.6	19.2	583.2	141.6
September	81.6	580.8	57.6	81.6	580.8	57.6	81.6	580.8	57.6
October	96	556.8	91.2	96	556.8	91.2	96	556.8	91.2
November	40.8	564	115.2	40.8	564	115.2	40.8	564	115.2
December	28.8	525.6	187.2	28.8	525.6	187.2	28.8	525.6	187.2
Total hours per year	496.8	5268	3000	496.8	5268	3000	496.8	5268	3000

Table 1.2: Direction of wind at the site of AnehoAmedjonoukou

	The direction of wind and as a function of time															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Wind Speed	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°
>0 m/s	0	0	0	1	0	0	0	0	2	0	150	0	1	0	1	0
>0.3 m/s	4	2	2	4	3	6	8	14	64	115	1277	61	42	11	8	4
>1.6 m/s	2	2	2	3	4	9	23	81	508	1756	735	163	36	4	2	2
>3.4 m/s	0	1	1	0	0	1	7	119	1187	1753	24	56	4	1	0	0
>5.5 m/s	0	0	0	0	0	0	0	11	318	177	0	0	0	0	0	0
>8 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The probabilities of occurrence of winds at the sites were determined using Weibull density probability function [11](1.2).

$$\mathbf{f(v)} = \frac{\mathbf{K}}{\mathbf{C}}\left(\frac{\mathbf{v}}{\mathbf{C}}\right)^{\mathbf{k-1}} . \mathbf{exp}\left(-\left(\frac{\mathbf{v}}{\mathbf{C}}\right)^{\mathbf{k}}\right) (1.2)$$

Where:
f (v) : is a probability density function,
K : is the shape parameter and is dimensionless ($1 \leq K \leq 10$),
C :is the scaling parameter in m/s ($1.5 \leq C \leq 3.0$),

ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

v:is the wind speed.

For the site of AnehoAmedjonoukou the graphical representation of the Weibull density probability function is in Figure 1.6. Knowing the parameters K and C of weibull, the graphical representation is obtained by using the Matlabsoftware.

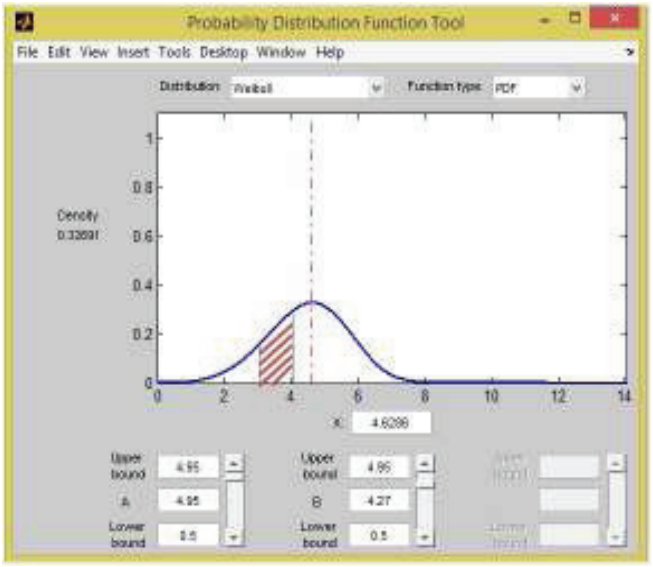

Figure 1.6: Weibull distribution function

The value of the surface of the area under the curve, hatched in red, between wind speeds 3-4 m/s, greater than zero, is the probability P that the wind blows somewhere between these two speeds. To determine this area the primitive of the Weibull density distribution function in formula (1.3) is used, it graphic representation shows by the Figure 1.7 is obtained by Matlab.

$$\begin{cases} \mathbf{F(V) = 1 - \exp\left(-\left(\frac{V}{C}\right)^{k}\right)} \\ \mathbf{P(A - B) = F(B) - F(A)}\text{, with } \mathbf{B} > A \end{cases} \quad (1.3)$$

Withthis function F, the probabilitywas determined for the site of AnehoAmedjonoukou that the wind blows in each interval of wind speed as presented in table 2.3.

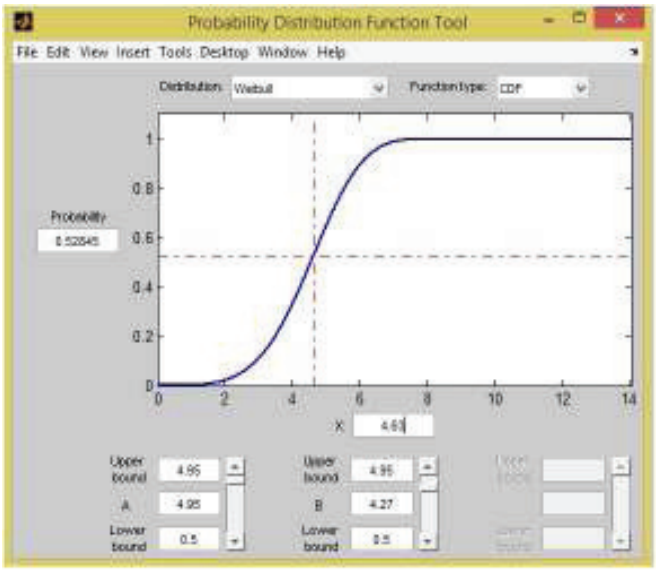

Figure 1.7: The primitive of the Weibull distribution probability function.

3.3. Daily Data of Wind Speeds and Directions

The data cover the period from 23/02/2017 to 25/04/2017. The analysis of this data allowed gauging the analysis of the annual data. The downloaded data is raw data that have beenvalidated. The extract of the validated data of the first 6 hours of the day of 1 March 2017 of the site of AnehoAmedjonoukou is presented in Table 1.3. From these data in Table 1.3, Windographer software was used for processing.The expected results of these analyzes are: climatic conditions on the seven sites (resulting from the analysis of annual and geographic data), wind characteristics on the seven sites at 10m height agl(resulting from the analysis of annual data And daily), and at the end, the probabilities of the appearance of the wind on the seven sites at the height of 10m height (resulting from the analysis of the annual data).

Table 1.3: wind speeds and direction at the site of AnehoAmedjonoukou

Date	Time	80mWS	80m WD	10mWS	10m WD	Pressure	Temperature
030117	0000	6.2	238.328	4.79	109.9022	1010	27.24
030117	0100	5.66	181.3215	4.7	103.823	1009.3	26.9
030117	0200	5.46	162.7713	4.53	92.95968	1008.4	26.51
030117	0300	4.74	106.4964	4.19	73.56006	1008.3	26.73
030117	0400	4.52	92.34541	3.88	58.41107	1008.3	27.04
030117	0500	4.02	64.96481	3.58	45.88271	1008.5	27.12
030117	0600	3.44	40.70758	2.92	24.89709	1008.8	26.37

III. Results and Interpretation

The results of the studies are the maps of average wind power density of Togo at 10m height above ground level, the results of the quantitative study of evaluation of the wind potential at 10m height above ground level on the seven sites is summarized in tables 2.1, 2.2 and 2.3.

A. Wind Power Density ofTogo

Average wind power density in Togo range from 7-94 W / m² as shown in Figures 2.1 and 2.2.

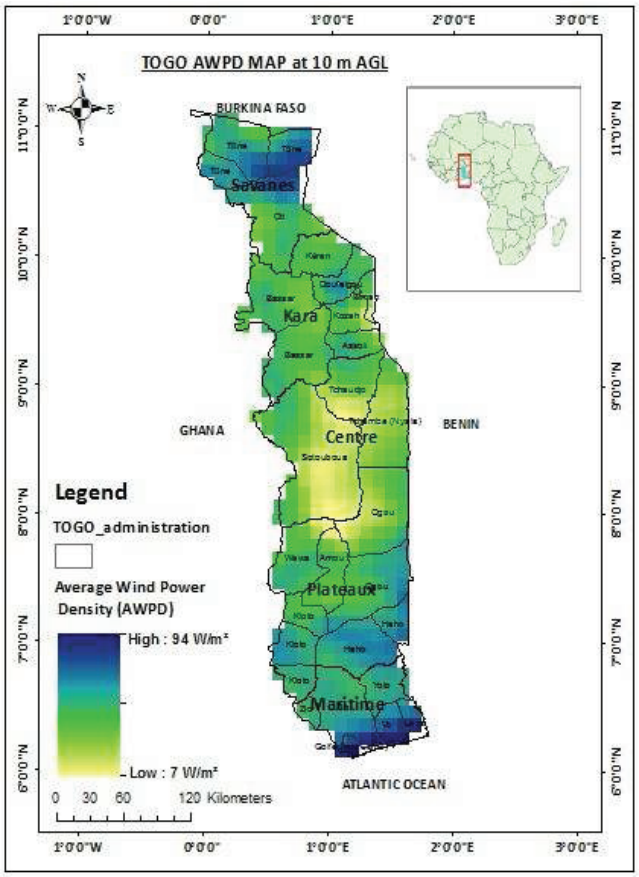

Figure 2.1:Map of average wind power density at 10m height aglin Togo

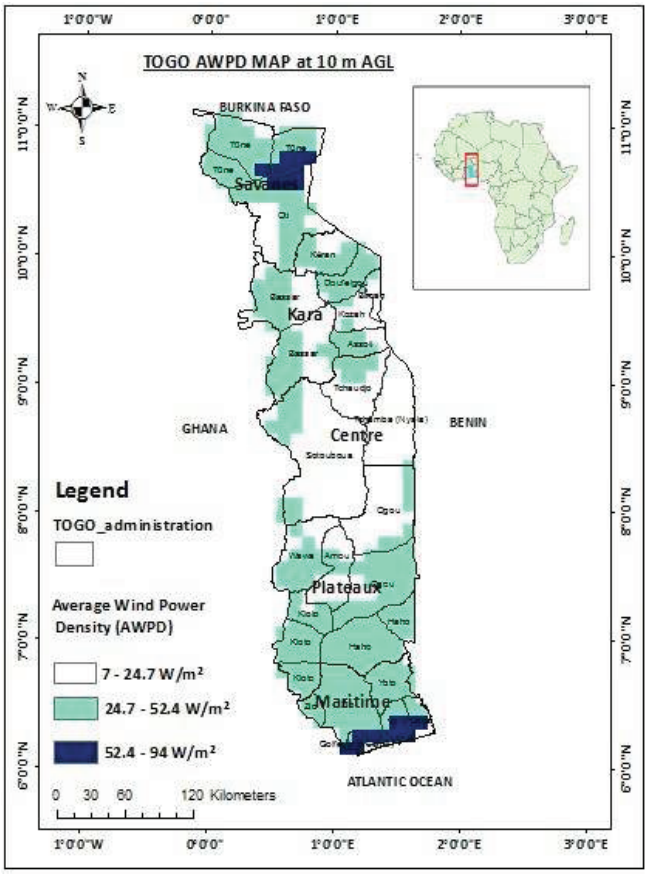

Figure 2.2: Map of average wind power density at 10m height agl reclassified in Togo

More than 39.5% of Togo's territory has an average power density of between 7-24.7W/m². In the same moment 58.5% of it territory has a density of 24.7-52.4W/m² and 2% has a power density of 52.4-94W/m².

B. Wind Site Profiles

The summary of the wind profiles of the seven sites are the climatic conditions on the sites, the wind characteristics on the seven sites at 10m height agl and the probability of occurrence of the winds on the seven sites at the same level. The seven sites AnehoAmedjonoukou, AnieAdeourou, KanteAnimene Tie, KanteTitira, Kara Sondina, NiamtougouAliandeKadjala and NotseVedome are named respectively Site1, Site2, Site3, Site4, Site5, Site6 and Site7 in the tables 2.1, 2.2 and 2.3.

ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

Table 2.1: Environment conditions at the seven sites

Name of site	Site1	Site2	Site3	Site4	Site5	Site6	Site7
Latitude	6°16'11.02"	7°47'06.00"	10°01'35.89 "	9°59'09.85"	9°27'39.66"	9°48'32.40"	6°50'24.00"
Longitude	1°34'42.94"	1°00'00.00"	1°08'19.69"	1°07'09.11"	1°00'00.00"	1°00'00.00"	1°00'00.00"
Elevation	21m amsl	370m amsl	194m amsl	193m amsl	283m amsl	244m amsl	145m amsl
Time	1 Year	1 Year	1 Year	1 Year	1 Year	1 Year	1 Year
Mean Pression	1.009 bar	1.009 bar	1.007 bar	1.007 bar	1.008 bar	1.007 bar	1.009 bar
Variation of Temperature	21°C - 36°C	18°C - 38°C	16°C - 39°C	17°C - 42°C	18°C - 40°C	17°C - 41°C	21°C - 39°C
Variation of precipitation	3 - 43mm	6 - 257mm	1- 51mm	0 - 51mm	1 - 128mm	0 - 114mm	4 - 142 mm
Surface roughness	0.00000013m	0.032 m	0.0899 m	0.0896 m	0.0516 m	0.0631 m	0.00000003m
Roughness class	0.00	1.05	1.91	1.91	1.45	0.62	0.00
Roughness description	Smooth	Fallowfield	Few trees	Few trees	Crops	Crops	Smooth

Table 2.2: Wind characteristics on the seven sites at 10mheight agl

Name of site	Site1	Site2	Site3	Site4	Site5	Site6	Site7
Predominant Wind Direction	157.5° to 202.5°	157.5° to 202.5°	157.5° to 202.5°	157.5° to 202.5°	157.5° to 202.5°	157.5° to 202.5°	180° to 202.5°
Average Wind speed	4.42 m/s	3.5 m/s	4.33 m/s	4.32 m/s	4.02 m/s	4.18 m/s	3.68 m/s
Standart Deviation of Wind speed	1.16	1.18	1.26	1.27	1.17	1.22	1.17
Turbulence Intensity	0.263	0.34	0.294	0.295	0.293	0.293	0.32
WeibullParameter C	4.95	3.9	4.84	4.84	4.51	4.67	4.12
WeibullParameter K	4.27	3.25	3.80	3.78	3.80	3.80	3.45
Energy Pattern Factor	1.21	1.36	1.26	1.23	1.26	1.23	1.31
Air Density	1.163 kg/m^3	1.164 kg/m^3	1.143 kg/m^3	1.143 kg/m^3	1.147 kg/m^3	1.144 kg/m^3	1.161 kg/m^3
Wind power density	62.12 W/m²	35.06 W/m²	60.49 W/m²	60.34 W/m²	48.92 W/m²	54.56 W/m²	39.08 W/m²
Power Law Index	0.052	0.149	1.176	0.176	0.16	0.165	0.0484

Table 2.3: Probabilities of the appearance of winds on the seven sites at the height of 10mheight agl

	Probability of occurrence of wind by speed interval sites						
Intervalle de vitesse de vent	Site1	Site2	Site3	Site4	Site5	Site6	Site7
3m/s à 4m/s	0.22	0.31	0.23	0.23	0.28	0.25	0.31
4m/s à 5m/s	0.32	0.24	0.29	0.29	0.30	0.30	0.26
5m/s à 6m/s	0.25	0.09	0.22	0.22	0.18	0.2	0.12
6m/s à 7m/s	0.09	0.02	0.09	0.09	0.05	0.07	0.02
3m/s à 5m/s	0.54	0.55	0.53	0.53	0.58	0.56	0.57
5m/s à 7m/s	0.34	0.11	0.31	0.31	0.22	0.27	0.14

C. DISCUSSION

For its own electricity production, Togo uses mostly petroleum products as primary sources, as it should be noted that hydroelectric production from Nagbeto Dam is not intended for Togo alone. Togo demonstrated its willingness to fight climate change by signing in September 2016 in New York, the Agreement resulting from the United Nations Climate Conference-COP 21-held in December 2015 in Paris [9]. Thus the energy department of Togo has receiveda mission from Togolese's Government to implement a renewable energy development policy to increase their share in the country's energy mix. Our study has contributed to the improvement of the knowledge about the wind potential of Togo. As a result, it is possible to use wind turbine in Togo to produce electricity in rural areas away from the traditional electricity grid. To demonstrate that Togo has wind potential favorable, the quantitative study of the wind potential of seven (07) sites in the country such as AnehoAmedjonoukou, AnieAdeourou, KanteAnimene Tie, KanteTitira, Kara Sondina, NiamtougouAliandeKadjala and NotseVedome at 10m height above ground level, was done. On more than 15% Togo's territory, wind power density ranges between 48-62W/m². An analysis of the results showed that Togo has the wind resource at 10m height agl to be valorized.

CONCLUSION

In this study it is shown that Togo has ability to use wind turbine technology in the production of electric power. This study reveals that Togo as a whole has a potential of which, the estimate of the average wind power density at 10m height agl ranges between 7 - 94W/m². On more than 60.47% of its territory, Togo has a power density ranges between 24.5 - 94 W/m², which are the areas suitable for the installation of wind turbines. 2% of the territory with very high wind potential at 10m height agl, located on the coast and in the north of the country have average power density which ranges between 52.4-94 W/m². In Togo, a high proportion of the population is agricultural and therefore lives in rural areas. The development of wind turbine technology will contribute to the well-being of the population by providing them with electric energy. These actions will help to curb the rural exodus of the population and bring an improvement in the social life of the populations. The seven sites selected for this study, are: AnehoAmedjonoukou, AnieAdeourou, KanteAnimene Tie, KanteTitira, Kara Sondina, NiamtougouAliandeKadjala and NotseVedome. A quantitative study of the wind potential on, the whole territory is a next step, which will allow having the real percentage of the wind resource in the Togo's energy mix.

ACKNOWLEDGMENT

M. Samah Bawong TCHODOU, The main author would like to thank, NAM S&T Centre Research Training Fellowship for Developing Country Scientists (RTF-DCS), Department of Science and Technology, Government of India, New Delhi for the financial support.

The main author also would like to thank National Institute of Wind Energy, Chennai for providing me necessary infrastructure facilities for completing the study.

The author would like to acknowledge MeteoBlue for providing wind data for various sites, which was useful to calculate the Wind potential of some sites in Togo.

REFERENCE

[1] Directorate General of Energy of Togo, DGE
[2] www.ecowrex.org/sites/default/files/documents/projects/2012_communique-de-presse_eco-delta.pdf
[3]Source: REN21 Renewable 2016 Global Status Report
[4]http://www.ecowrex.org/fr/node/13563
[5]https://www.meteoblue.com
[6]https://fr.wikipedia.org/wiki/Google_Maps
[7]https://en.wikipedia.org/wiki/Google_Earth
[6]https://en.wikipedia.org/wiki/Wind_resource_assessment
[8]https://fr.wikipedia.org/wiki/MATLAB
[9]http://www.financialafrik.com/2016/09/20/le-togo-signe-laccord-de-paris-sur-le-Climat/#.WQBEptxWS00
[10] http://eolienne.f4jr.org/eolienne_etude_theorique
[11] http://eolienne.f4jr.org/eolienne_etude_theorique.