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Wind velocity extrapolation in Ghana by Weibull probability density function

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Abstract

This article proposes a database of reliable wind velocities across the whole Ghana divided into 24 locations, based on data collected for the year 2013, although the bigger plan is to cover the period 2013–2018. For the year 2013 specifically, the proposed data were obtained through extrapolation of RETScreen data on wind velocity in Ghana, originally taken at a height of 10 m to a height of 60 m, adequate for generation using Weibull distribution function. The model led to the determination of the shape factor k and the scale factor c for all the 24 locations which subsequently led to the extrapolated wind velocity. The lowest and highest wind speeds were recorded, respectively, as 3.77 and 8.24 m/s for Wenchi and Wa locations in Ghana. The utmost relevance of this article is of national dimension to Ghana as the resulting wind velocities may be useful to undertake feasibility studies or real implementation of wind power plant.

Keywords

Wind velocity, extrapolation, Weibull distribution, RETScreen data

Introduction

Wind resource estimation is a fundamental requirement for wind power production. Wind velocity and direction are essential data that help predict the wind production capacity for a typical area. There is an apparent assumption on the existence of strong wind velocities in Ghana that can be exploited for wind power production.

However, the availability of the wind resource that is necessary for exploitation is still a big limitation. In Ghana, the Energy Commission is in charge of collecting wind data, but so far their coverage is limited to some few regions which are relatively insignificant compared to a nationwide data. The areas covered with wind data in Ghana by the Energy Commission are very limited (Seth and Modjinou, 2012). Some common areas that have witnessed wind turbine design in Ghana are Mankoadze and Anloga owing to their average annual wind speed of 6.1 and 5.4 m/s, respectively. The lack of data on wind added to many other factors contribute to the limitations of wind farm deployment for energy production in Ghana.

A survey of wind farm developed in Ghana shows a very limited number of available wind farms as depicted by the renewable energy map in Figure 1 (Seth and Modjinou, 2012).

There is a slow adoption of wind power production in Ghana as compared to countries such as Canada and Germany where wind production is at the apex. Wind power has grown steadily in Canada over the past 12 years with records of 6201 MW production in 2012, a figure considered as almost 5% of the total wind energy capacity in Canada. In 2013, there is an estimation of more than 3750 wind turbines generating electricity in 170 wind farms across the country (Adamek, 2010; Energy and Mines Ministers' Conference, 2013). All provinces and two territories have wind power turbines in operation, and three provinces (Ontario, Alberta, and Quebec) have passed over the 1000-MW threshold

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of installed capacity. Currently, the total wind power in Canada has attained a figure of 10,204 MW which represents 4% of the Canada electricity demand and this trend is expected to reach 20% by 2025 (CanWEA, 2008; Smith, 2009). Comparatively, there is an unprecedented delay in the adoption and deployment of wind power in Ghana. More attention is given to other renewable energies such as solar despite the great potential of the country in wind resource. It is therefore believed that the slow adoption of wind power plant in Ghana can be partly attributed to the lack of availability of reliable data on wind velocity which indirectly limit feasibility and wind energy deployment.

There is, therefore, a need to study wind speed variability in Ghana and provide a reasonable dataset that can help individual power producers and the national electricity companies at large. A 5-year study covering the period of 2013–2018 is being proposed to solve the problem. Treated wind data of each year in the period 2013–2018 are to be provided and analyzed with machine learning techniques applicable to big data. The first stage in this attempt to provide a comprehensive dataset on wind velocity in Ghana will consist of treating the year 2013 data.

This article seeks to address the above problem by adopting secondary data from the RETScreen International Software in the year 2013 that will be extrapolated with Weibull distribution function to provide an accurate estimate of wind resource in Ghana.

Background on RETScreen data

RETScreen is an energy management software created by the Government of Canada that helps predict the viability and feasibility of energy project including renewable energy sources.

According to Ganoe et al. (2014), the RETScreen Plus is a Windows-based energy management software tool that allows project owners to easily verify the ongoing energy performance of their facilities. It is developed by the Ministry of Energy in Canada in collaboration with NASA. Leng (1999) further describes the RETScreen software as one that can be used worldwide to evaluate the energy production, life-cycle costs, and greenhouse gas emission reductions for various types of RETs. The latest version of the software known as RETScreen Expert provides more options in designing and monitoring energy projects.

It is essential to realize that the RETScreen Climate Database includes meteorological data and climate data from ground monitoring stations that are mostly obtained from NASA. The RETScreen makes use of full dataset on climate and map that covers the entire surface of the planet (Moujaled, 2014). The dataset provided by NASA is very reliable and can easily be exploited for wind plant production when it is properly extrapolated to the desired height.

The RETScreen user is able to automatically download historical and near real-time data from NASA's web servers and directly upload them into the data section of the Performance Analysis Module. This makes weather-related data collection very simple task in the world. Figure 2 shows an interface of RETScreen Plus software providing data for Tema, Ghana.

Method of wind velocity estimation

The method includes first an extrapolation of wind data collected from a height 10 m to a height of 60 m followed by the development of the probability density function (PDF) using the Weibull model.

Data extrapolation

A technique known as extrapolation helps determine with some level of accuracy the equivalent wind speed at different heights. For instance, it will be very convenient to extrapolate the RETScreen data, originally collected at a height of 10 m to a height of 60 m appropriate for wind energy production in Ghana. According to empirical studies conducted by Justus et al. (1978) and Manwell et al. (2009), the wind speed at a desired height Z can be evaluated as follows using the power law model

$$V_w(Z) = \left(\frac{Z}{Z_{ref}}\right)^{\alpha} \cdot V_w(Z_{ref}) \tag{1}$$

where

$$\alpha = \frac{0.37 - 0.088 \cdot \ln\left(V_w(Z_{ref})\right)}{1 - 0.088 \cdot \ln\left(\frac{Z_{ref}}{10}\right)} \tag{2}$$

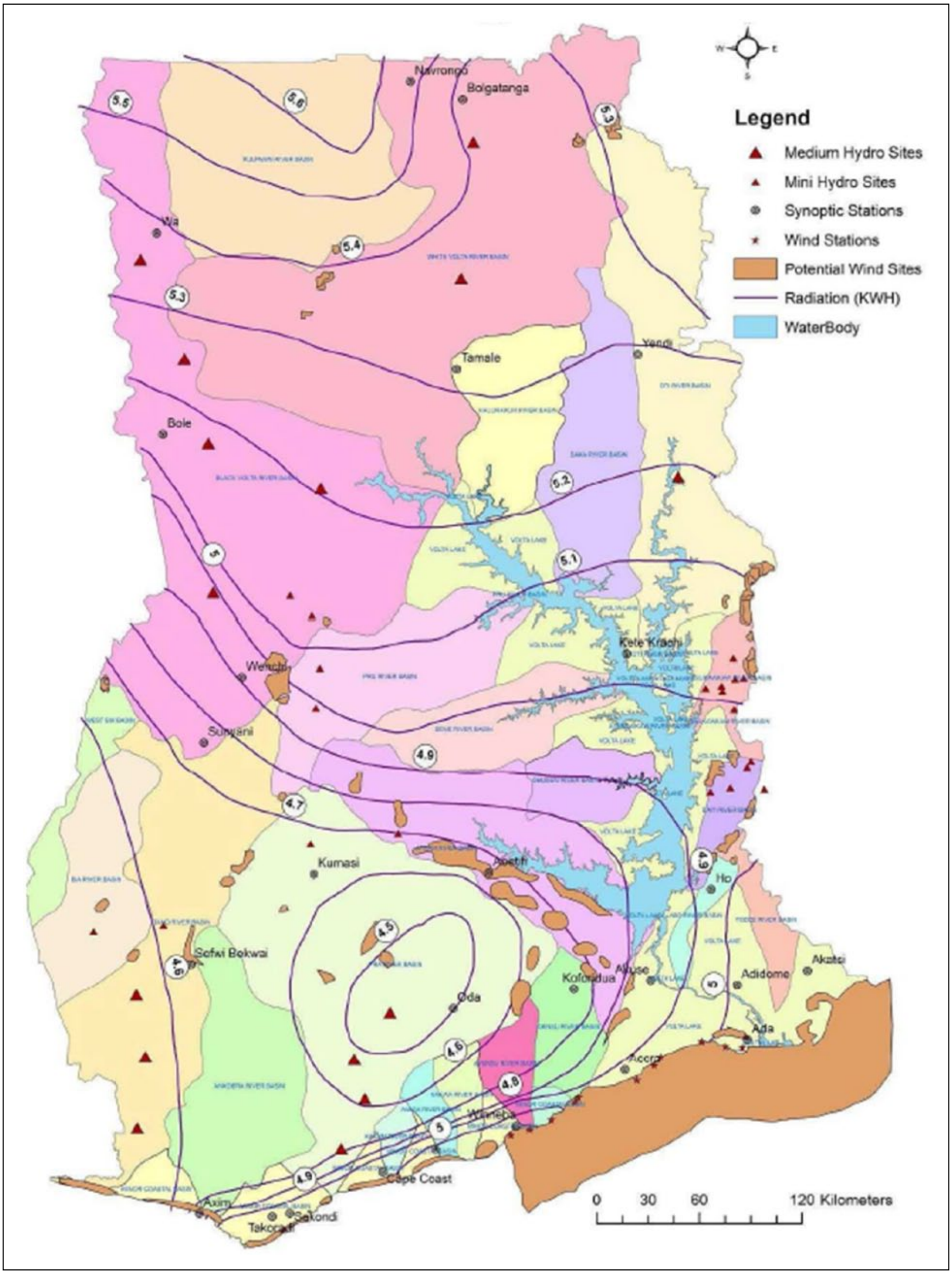
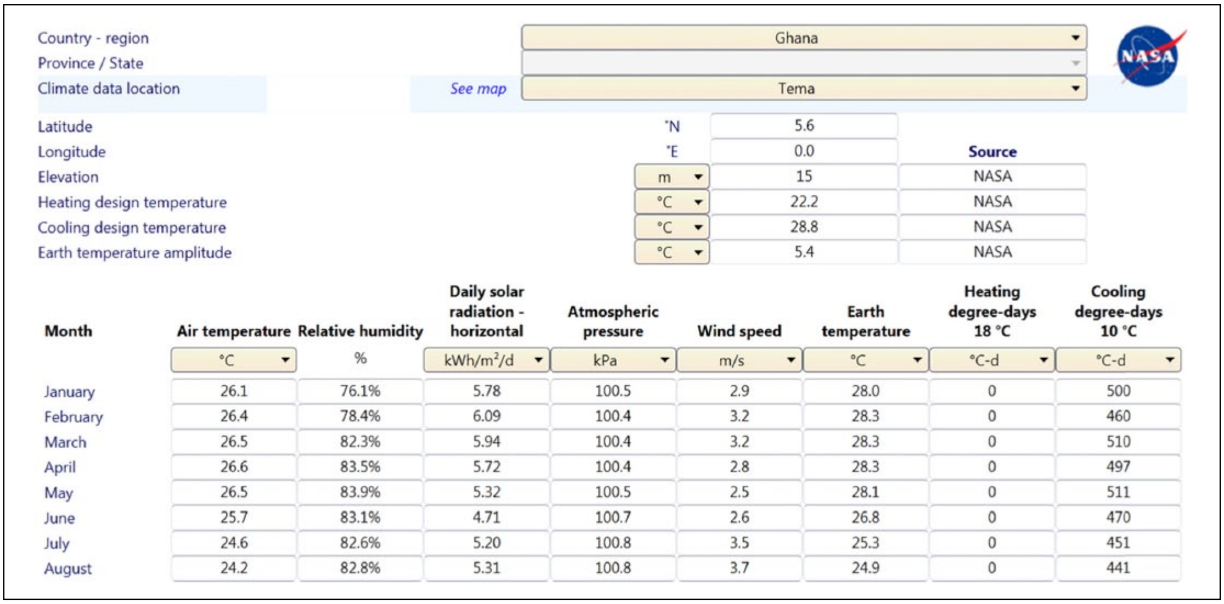


Figure 1. Renewable energy map of Ghana (Seth and Modjinou, 2012).

where Z is the desired height, 60 m in the case of this study; Z_{ref} is the reference height where original data are collected; $V_w(Z)$ is the wind speed at height Z; and $V_w(Z_{ref})$ is the wind speed at height Z_{ref}. These data will be provided directly from the RETScreen software. α is the power law exponent.

For a reference height of 10 m as indicated in the RETScreen software

$$\alpha = 0.37 - 0.088 \cdot \ln\left(V_w(Z_{ref})\right) \tag{3}$$



Country - region		Ghana	
Province / State			
Climate data location	See map	Tema	
Latitude	°N	5.6	
Longitude	°E	0.0	Source
Elevation	m	15	NASA
Heating design temperature	°C	22.2	NASA
Cooling design temperature	°C	28.8	NASA
Earth temperature amplitude	°C	5.4	NASA

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	76.1%	5.78	100.5	2.9	28.0	0	500
February	26.4	78.4%	6.09	100.4	3.2	28.3	0	460
March	26.5	82.3%	5.94	100.4	3.2	28.3	0	510
April	26.6	83.5%	5.72	100.4	2.8	28.3	0	497
May	26.5	83.9%	5.32	100.5	2.5	28.1	0	511
June	25.7	83.1%	4.71	100.7	2.6	26.8	0	470
July	24.6	82.6%	5.20	100.8	3.5	25.3	0	451
August	24.2	82.8%	5.31	100.8	3.7	24.9	0	441

Figure 2. RETScreen Plus data provided for the location Tema, Ghana.
Source: RETScreen Plus Software, 2013.

Therefore, the wind speed estimated at 60 m height will be obtained as follows by replacing α in equations (1) and (2) with its expression obtained in equation (3)

$$V_w(Z) = \left(\frac{60}{10}\right)^{\left(0.37-0.088\cdot\ln\left(V_w(Z_{ref})\right)\right)} \cdot V_w(Z_{ref}) \tag{4}$$

$$V_w(Z) = 6^{\left(0.37-0.088\cdot\ln\left(V_w(Z_{ref})\right)\right)} \cdot V_w(Z_{ref}) \tag{5}$$

Development of PDF for the extrapolated wind data

The estimation of wind energy is based on the knowledge of the average speed and the wind speed distribution function. With reference to Manwell et al. (2009), RETScreen International (2004), and Essandoh (2012), the wind speed distribution can be estimated using the Weibull PDF described below. Another possibility is the use of Rayleigh PDF which can be considered as a special case of the Weibull PDF under some conditions (scale factor k = 2).

The Weibull PDF is used to express the probability of getting a wind speed V_w during the year, as follows (Manwell et al., 2009)

$$p\left(V_w\right) = \left(\frac{k}{c}\right)\cdot\left(\frac{V_w}{c}\right)^{k-1}\cdot\exp\left(-\left(\frac{V_w}{k}\right)^{k}\right) \tag{6}$$

The cumulative PDF is also expressed as follows

$$F(U) = 1-\exp\left(-\left(\frac{V_w}{k}\right)^{k}\right) \tag{7}$$

where k is known as the shape factor and c as the scale factor. The expression of the PDF is valid for $k > 1$, $V_w \geqslant 0$, and $c > 0$.

With knowledge of the average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. Based on empirical functions established by Justus et al. (1978), the shape and scale factors can be expressed as follows

Table 1. 2013 RETScreen Plus data for Accra, Akuse, Axim, and Bawku locations in Ghana.

Month	Accra				Akuse				Axim				Bawku			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	4.1	2.6	4.34	27.4	4.08	2.7	4.48	28.8	5.67	3.7	5.84	27.3	5.39	2.3	3.91	28.5
February	4.59	2.6	4.34	27.8	4.78	2.8	4.62	28.8	6.14	3.8	5.97	27.5	5.96	2.2	3.77	30.8
March	5.21	2.6	4.34	28	5.06	3	4.90	27.9	5.87	3.6	5.71	28	6.21	2.7	4.48	33.8
April	5.08	2.6	4.34	28.1	5.3	2.6	4.34	27.5	5.69	3.3	5.30	28.3	6.3	2.6	4.34	33.3
May	5.02	2.1	3.63	27.9	5.15	2.4	4.06	27	5.11	3	4.90	28	6.09	2.8	4.62	30.9
June	3.97	2.1	3.63	26.6	4.67	2.3	3.91	25.9	4.42	3.3	5.30	26.7	5.61	2.5	4.20	28.1
July	3.7	4.6	7.02	25	4.03	3.1	5.03	24.8	5.14	3.9	6.11	25.3	5.22	2.5	4.20	26.1
August	3.84	5.1	7.65	24.6	4.14	3.2	5.17	25	5.17	3.9	6.11	24.8	4.94	2.3	3.91	25.9
September	4.59	5.1	7.65	25.1	4.73	3.2	5.17	25.4	5.21	3.7	5.84	25.3	5.27	1.9	3.33	26.9
October	5.19	2.6	4.34	26.2	5.11	2.6	4.34	25.9	5.79	3.4	5.44	26.2	5.73	1.9	3.33	29.6
November	4.79	4.6	7.02	27.2	4.84	2.9	4.76	26.7	5.98	3	4.90	27.2	5.47	2.1	3.63	31.1
December	3.86	2.1	3.63	27.3	4.06	2.3	3.91	27.7	5.55	3.3	5.30	27.4	5.3	2.2	3.77	28.8

$$k = \left(\frac{\sigma_{V_w}}{V_w} \right)^{-1.086} \tag{8}$$

$$c = \frac{\bar{V}_w}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{9}$$

$\Gamma(x)$ is the Gamma function; σ_{V_w} is the standard deviation of the individual wind speed averages; $\bar{V}_w$ is the average wind speed.

The latter two parameters can also be evaluated with the formula below where N represents the number of sampled wind velocity

$$\bar{V}_w = \frac{1}{N} \sum_{i=1}^{N} V_{w_i} \tag{10}$$

$$\sigma_{V_w} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (V_{wi} - \bar{V}_w)^2} \tag{11}$$

Knowing the wind probability distribution regime, the average wind power over a period T can be expressed as follows

$$\bar{P}_w = \int_0^T P_w(V_w) \cdot p(V_w) dV_w \tag{12}$$

where $P_w(V_w)$ and $p(V_w)$ represent, respectively, the wind power and the probability distribution function for a velocity V_w.

Results and discussion

A summary of data collected from RETScreen including the extrapolated wind speed at 60 m height is first presented, followed by the display of the probability distribution function developed using the wind speed collected in the 24 selected locations in Ghana. The summary of data collected in Ghana for this study is presented in Tables 1 to 7. In Tables 1 to 7, SR represents solar radiation (kW h/m^2/day), WS is the wind speed (m/s), and T is the temperature (°C).

Table 2. 2013 RETScreen Plus data for Bibiani, Bole, Bolgatanga, and Cape Coast locations in Ghana.

Month	Bibiani				Bole				Bolgatanga				Cape Coast			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	5.3	2.4	4.06	25.9	5.04	2.1	3.63	29.5	5.72	2.2	3.77	29.5	5.19	2.8	4.62	26.8
February	5.49	2.5	4.20	26.3	5.49	2	3.48	30.6	5.96	2.1	3.63	31.4	5.3	2.9	4.76	27.1
March	5.43	2.5	4.20	26.6	5.39	2.5	4.20	30.6	6.11	2.6	4.34	32.7	5.37	2.9	4.76	27.6
April	5.34	2.3	3.91	26.8	5.2	2.5	4.20	28.6	6.06	2.5	4.20	31	5.22	2.7	4.48	27.8
May	5.12	2.2	3.77	26.4	5.46	2.5	4.20	27.5	5.82	2.7	4.48	29.2	4.82	2.4	4.06	27.5
June	4.47	2.2	3.77	25.2	5.12	2.5	4.20	26.1	5.32	2.5	4.20	27	4.17	2.4	4.06	26.2
July	4.09	2.5	4.20	24.3	4.24	2.5	4.20	25	4.88	2.4	4.06	25.6	4.13	3.1	5.03	24.7
August	3.83	2.4	4.06	24	3.83	2.5	4.20	24.8	4.61	2.3	3.91	25.5	4.04	3.2	5.17	24.3
September	3.94	2.1	3.63	24.5	4.44	2	3.48	25.6	4.95	2	3.48	26.3	4.09	3	4.90	24.9
October	4.57	2.1	3.63	25	5.04	2	3.48	27	5.58	1.9	3.33	28.4	4.67	2.7	4.48	25.9
November	4.98	1.9	3.33	25.3	4.76	2.4	4.06	29.2	5.56	2.2	3.77	30.5	4.91	2.6	4.34	26.8
December	5	2.3	3.91	25.2	4.28	2.4	4.06	29.3	5.59	2.3	3.91	29.4	4.91	2.5	4.20	26.7

Table 3. 2013 RETScreen Plus data for Ejura, Hohoe, Kete Krachi, and Kintampo locations in Ghana.

Month	Ejura				Hohoe				Kete Krachi				Kintampo			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	5.54	2.3	3.91	28.3	5.66	2.6	4.34	29.5	5.61	2.4	4.06	29.2	5.58	2.2	3.77	29.6
February	5.81	2.1	3.63	28.3	5.93	2.3	3.91	29.4	5.8	2.2	3.77	29	6	2	3.48	29.8
March	5.75	2.5	4.20	27.8	5.78	2.7	4.48	28.2	5.88	2.6	4.34	28.1	6	2.5	4.20	29.2
April	5.61	2.2	3.77	27.2	5.61	2.3	3.91	27.3	5.74	2.2	3.77	27.4	5.87	2.2	3.77	27.9
May	5.25	2.4	4.06	26.8	5.26	2.5	4.20	26.9	5.47	2.5	4.20	26.9	5.6	2.5	4.20	27.4
June	4.7	2.2	3.77	25.7	4.58	2.1	3.63	25.8	4.89	2.1	3.63	25.9	4.92	2.3	3.91	26.1
July	4.25	2.4	4.06	24.8	4.15	2.5	4.20	24.8	4.55	2.4	4.06	24.9	4.5	2.3	3.91	25.1
August	3.96	2.3	3.91	24.7	4.04	2.6	4.34	25	4.38	2.4	4.06	25	4.24	2.2	3.77	25
September	4.1	2.2	3.77	25.2	4.25	2.6	4.34	25.4	4.55	2.4	4.06	25.4	4.5	2	3.48	25.7
October	4.72	2.1	3.63	25.8	4.84	2.2	3.77	26	5.19	2.2	3.77	26	5.17	2	3.48	26.6
November	5.03	2.1	3.63	26.6	5.31	2.5	4.20	27.1	5.4	2.3	3.91	27.2	5.46	2.1	3.63	28.3
December	5.21	2.1	3.63	27.3	5.37	2.1	3.63	28.4	5.38	2.1	3.63	28.2	5.54	2.2	3.77	28.9

Table 4. 2013 RETScreen Plus data for Koforidua, Kumasi, Navrongo, and Prestea locations in Ghana.

Month	Koforidua				Kumasi				Navrongo				Prestea			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	5.41	2.4	4.06	27.9	4.18	1.5	2.73	26.7	6.61	2	3.48	29.6	5.11	2.8	4.62	26.1
February	5.62	2.5	4.20	27.9	4.68	2.1	3.63	26.9	6.53	2	3.48	31.6	5.23	2.9	4.76	26.4
March	5.63	2.8	4.62	27.5	5.04	2.1	3.63	27	6.4	2.6	4.34	33.1	5.23	2.8	4.62	26.8
April	5.51	2.4	4.06	27.2	5.09	2.1	3.63	26.9	6.38	2.5	4.20	31.1	5.15	2.6	4.34	27
May	5.18	2.3	3.91	26.8	4.97	2.1	3.63	26.5	6.46	2.7	4.48	29.1	4.8	2.3	3.91	26.6
June	4.64	2.1	3.63	25.6	4.38	2.1	3.63	25.4	6.09	2.5	4.20	27	4.02	2.4	4.06	25.3
July	4.41	2.9	4.76	24.6	3.67	2.6	4.34	24.4	5.66	2.5	4.20	25.6	4.05	2.9	4.76	24.4
August	4.27	3	4.90	24.7	3.35	2.1	3.63	24.4	4.94	2.4	4.06	25.4	3.92	2.8	4.62	24.3
September	4.39	3	4.90	25.1	3.8	2.1	3.63	24.8	5.47	1.9	3.33	26.4	3.87	2.6	4.34	24.8
October	4.96	2.5	4.20	25.6	4.44	2.1	3.63	25.3	6.19	1.9	3.33	28.7	4.54	2.5	4.20	25.3
November	5.09	2.7	4.48	26.3	4.66	1.5	2.73	25.7	6.15	2.1	3.63	31	4.88	2.2	3.77	25.8
December	5.16	2.1	3.63	26.9	3.87	1.5	2.73	25.9	5.98	2.2	3.77	29.7	4.88	2.6	4.34	25.7

Table 5. 2013 RETScreen Plus data for Salaga, Sunyani, Tafo, and Takoradi locations in Ghana.

Month	Salaga				Sunyani				Tafo				Takoradi			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	5.63	2.4	4.06	29.8	5.49	2.2	3.77	27.1	3.82	2.4	4.06	27.9	4.45	2.6	4.34	27.7
February	5.91	2.1	3.63	30	5.67	2.1	3.63	27.3	4.04	2.5	4.20	27.9	5.15	3.6	5.71	28.1
March	6.03	2.6	4.34	29.2	5.63	2.5	4.20	27.1	4.45	2.8	4.62	27.5	5.55	4.1	6.37	28.6
April	5.8	2.2	3.77	27.9	5.45	2.3	3.91	26.8	4.74	2.4	4.06	27.2	5.42	3.6	5.71	28.9
May	5.53	2.6	4.34	27.3	5.14	2.4	4.06	26.5	4.52	2.3	3.91	26.8	5.08	2.6	4.34	28.9
June	4.93	2.2	3.77	26.1	4.49	2.2	3.77	25.4	3.91	2.1	3.63	25.6	4.29	2.6	4.34	27.4
July	4.58	2.2	3.77	25.1	3.97	2.4	4.06	24.4	3.44	2.9	4.76	24.6	4.15	3.1	5.03	25.5
August	4.31	2.1	3.63	25.1	3.69	2.2	3.77	24.1	3.33	3	4.90	24.7	4	3.1	5.03	24.7
September	4.59	2	3.48	25.7	3.83	2	3.48	24.7	3.61	3	4.90	25.1	4.63	3.6	5.71	25.3
October	5.21	2	3.48	26.6	4.4	2	3.48	25.3	4.16	2.5	4.20	25.6	5.44	4.1	6.37	26.7
November	5.49	2.1	3.63	28.2	4.82	2	3.48	25.6	4.45	2.7	4.48	26.3	5.69	3.1	5.03	28.1
December	5.49	2.1	3.63	29	5.08	2.1	3.63	26	3.79	2.1	3.63	26.9	4.78	2.6	4.34	28.2

Table 6. 2013 RETScreen Plus data for Tamale, Tema, Wa, and Wenchi locations in Ghana.

Month	Tamale				Tema				Wa				Wenchi			
	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T	SR	WS at 10 m	WS at 60 m	T
January	5.13	2.6	4.34	31	5.78	2.9	4.76	28	5.73	5.73	8.44	29.2	4.05	2.2	3.77	27.1
February	5.55	2.1	3.63	31	6.09	3.2	5.17	28.3	6.02	6.02	8.80	31.3	4.64	2.1	3.63	27.3
March	5.74	2.6	4.34	29.1	5.94	3.2	5.17	28.3	6.15	6.15	8.96	32.7	4.78	2.5	4.20	27.1
April	5.62	2.1	3.63	28.1	5.72	2.8	4.62	28.3	6.1	6.1	8.90	30.6	4.76	2.3	3.91	26.8
May	5.7	2.6	4.34	26.5	5.32	2.5	4.20	28.1	5.96	5.96	8.73	28.5	4.62	2.4	4.06	26.5
June	5.31	2.1	3.63	25.3	4.71	2.6	4.34	26.8	5.46	5.46	8.11	26.5	4.16	2.2	3.77	25.4
July	4.62	2.1	3.63	25.3	5.2	3.5	5.57	25.3	4.92	4.92	7.43	25.3	3.51	2.4	4.06	24.4
August	4.24	2.1	3.63	25.3	5.31	3.7	5.84	24.9	4.67	4.67	7.11	25.1	3.23	2.2	3.77	24.1
September	4.76	2.1	3.63	26	5.29	3.6	5.71	25.5	5.01	5.01	7.54	26	3.62	2	3.48	24.7
October	5.47	2.1	3.63	27.3	5.64	2.9	4.76	26.4	5.6	5.6	8.28	28.2	4.24	2	3.48	25.3
November	5.44	2.1	3.63	29.4	5.69	3.1	5.03	27.5	5.59	5.59	8.27	30.6	4.31	2	3.48	25.6
December	4.76	2.1	3.63	29.4	5.56	2.6	4.34	27.8	5.63	5.63	8.32	29.3	3.77	2.1	3.63	26

Table 7. 2013 RETScreen Plus data on latitude, longitude, and elevation for various locations in Ghana.

S/N	Sites	Latitude (°N)	Longitude (°E)	Elevation (m)
1	Accra	5.6	−0.2	68
2	Akuse	6.1	0.1	19
3	Axim	4.9	−2.2	5
4	Bawku	11.1	−0.2	232
5	Bibiani	6.5	−2.3	207
6	Bole	9.0	−2.5	301
7	Bolgatanga	10.8	−0.9	194
8	Cape Coast	5.1	−1.3	111
9	Ejura	7.4	−1.4	237
10	Hohoe	7.2	0.5	298
11	Kete Krachi	7.8	0	132
12	Kintampo	8.1	−1.7	140
13	Koforidua	6.1	−0.3	219
14	Kumasi	6.7	1.6	287

(Continued)

Table 7. (Continued)

S/N	Sites	Latitude (°N)	Longitude (°E)	Elevation (m)
15	Navrongo	10.9	−1.1	203
16	Prestea	5.4	−2.2	109
17	Salaga	8.5	−0.5	125
18	Sunyani	7.3	−2.4	273
19	Tafo	6.3	−0.4	195
20	Takoradi	4.9	−1.8	5
21	Tamale	9.5	−0.9	168
22	Tema	5.6	0.0	15
23	Wa	10.1	−2.5	270
24	Wenchi	7.8	−2.1	340

Table 8. Parameters of the probability distribution function for Accra, Akuse, Axim, Bawku, Bibiani, and Bole.

	Accra	Akuse	Axim	Bawku	Bibiani	Bole
Mean (m/s)	5.16	4.56	5.56	3.96	3.89	3.95
SD	1.65	0.46	0.43	0.42	0.27	0.33
Shape factor k	3.46	12.11	16.08	11.43	17.86	15.04
Scale factor c	5.74	4.75	5.75	4.14	4.01	4.09

Table 9. Parameters of the probability distribution function for Bolgatanga, Cape Coast, Ejura, Hohoe, Kete Krachi, and Kintampo.

	Bolgatanga	Cape Coast	Ejura	Hohoe	Kete Krachi	Kintampo
Mean (m/s)	3.92	4.57	3.83	4.08	3.94	3.78
SD	0.35	0.37	0.20	0.30	0.23	0.25
Shape factor k	13.87	15.44	24.95	17.21	22.17	19.18
Scale factor c	4.07	4.73	3.91	4.21	4.03	3.89

Table 10. Parameters of the probability distribution function for Koforidua, Kumasi, Navrongo, Prestea, Salaga, and Sunyani.

	Koforidua	Kumasi	Navrongo	Prestea	Salaga	Sunyani
Mean (m/s)	4.28	3.46	3.87	4.36	3.79	3.77
SD	0.45	0.49	0.42	0.33	0.30	0.25
Shape factor k	11.48	8.45	11.28	16.60	15.82	19.39
Scale factor c	4.47	3.67	4.05	4.50	3.92	3.87

Table 11. Parameters of the probability distribution function for Tafo, Takoradi, Tamale, Tema, Wa, and Wenchi.

	Tafo	Takoradi	Tamale	Tema	Wa	Wenchi
Mean (m/s)	4.28	5.19	3.80	4.96	8.24	3.77
SD	0.45	0.77	0.32	0.55	0.60	0.25
Shape factor k	11.48	7.93	14.55	10.85	17.08	19.39
Scale factor c	4.47	5.52	3.94	5.20	8.50	3.87

The frequency distribution function makes use of some of the parameters including mean, standard deviation, shape factor, and scale factor. Tables 8 to 11 present a summary of the above-mentioned parameters for the 24 selected locations. The PDF is further plotted in graphs and displayed below for the same locations in Figures 3 to 8.

Although there is lack of empirical data to confirm the reliability of the results through statistical test such as the Kolmogorov–Smirnov test used by Şen et al. (2012), there is assurance and confidence in the RETScreen data used,

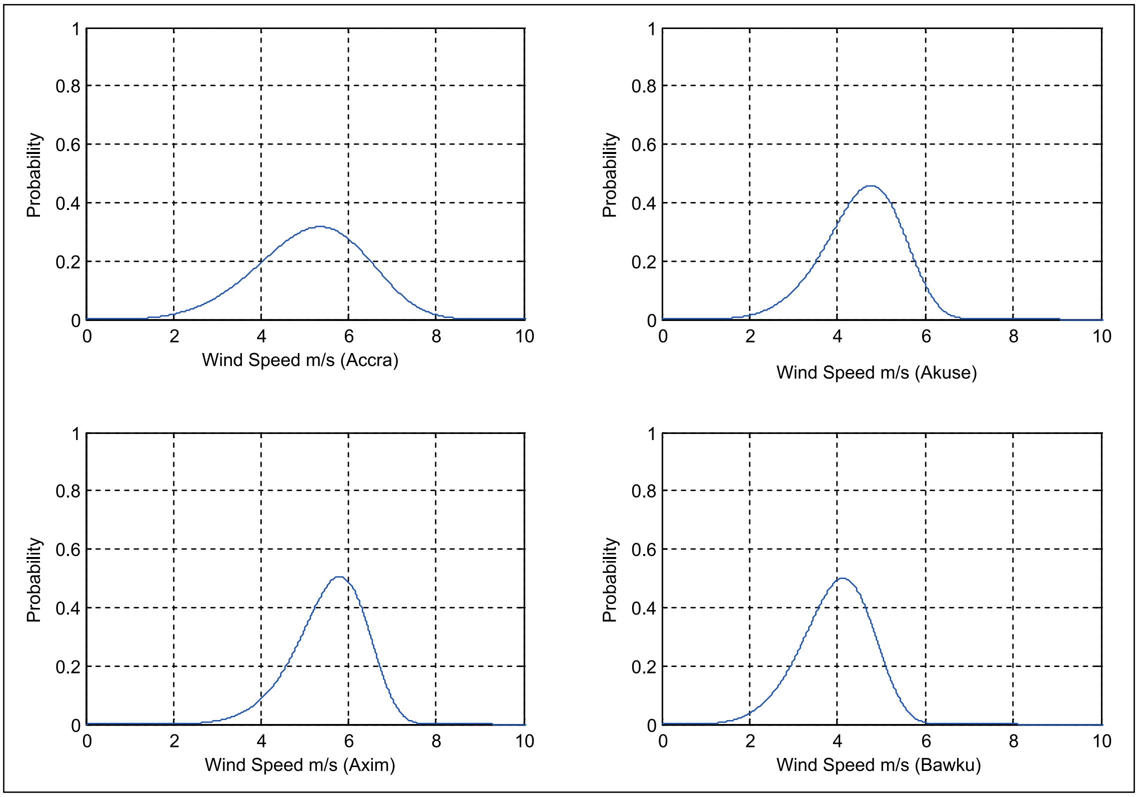


Figure 3. Probability distribution function for Accra, Akuse, Axim, and Bawku.

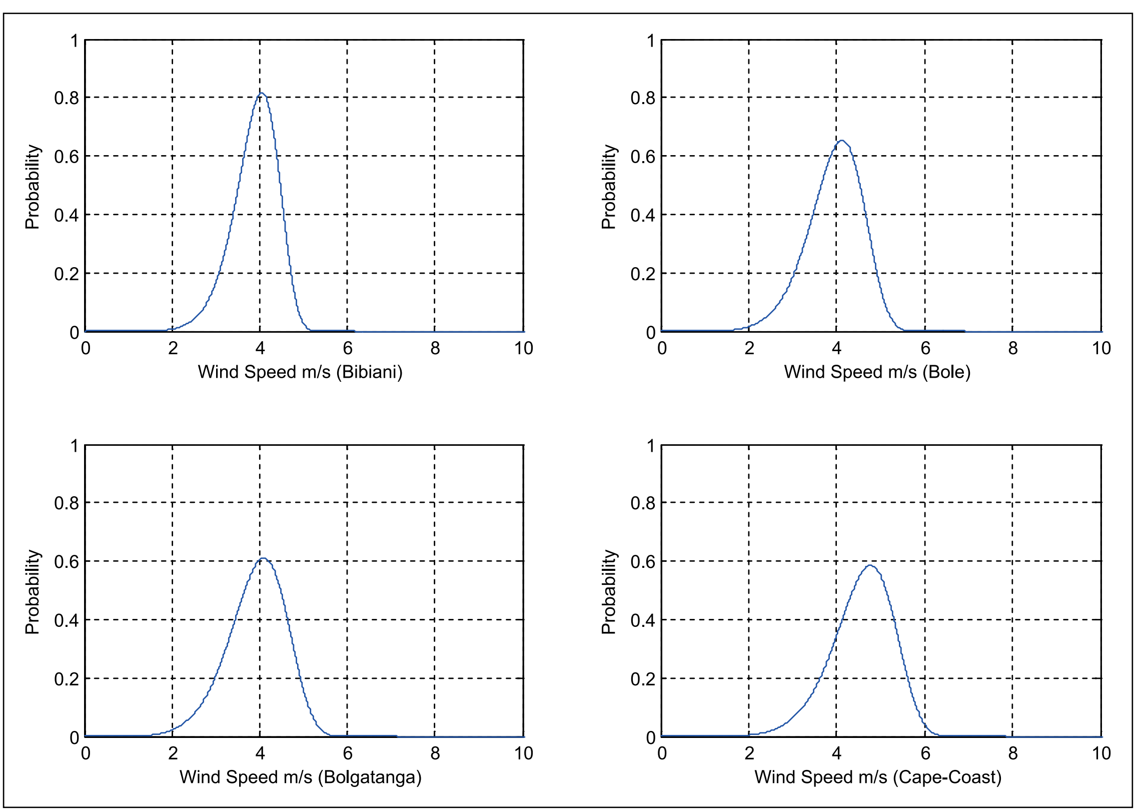


Figure 4. Probability distribution function for Bibiani, Bole, Bolgatanga, and Cape Coast.

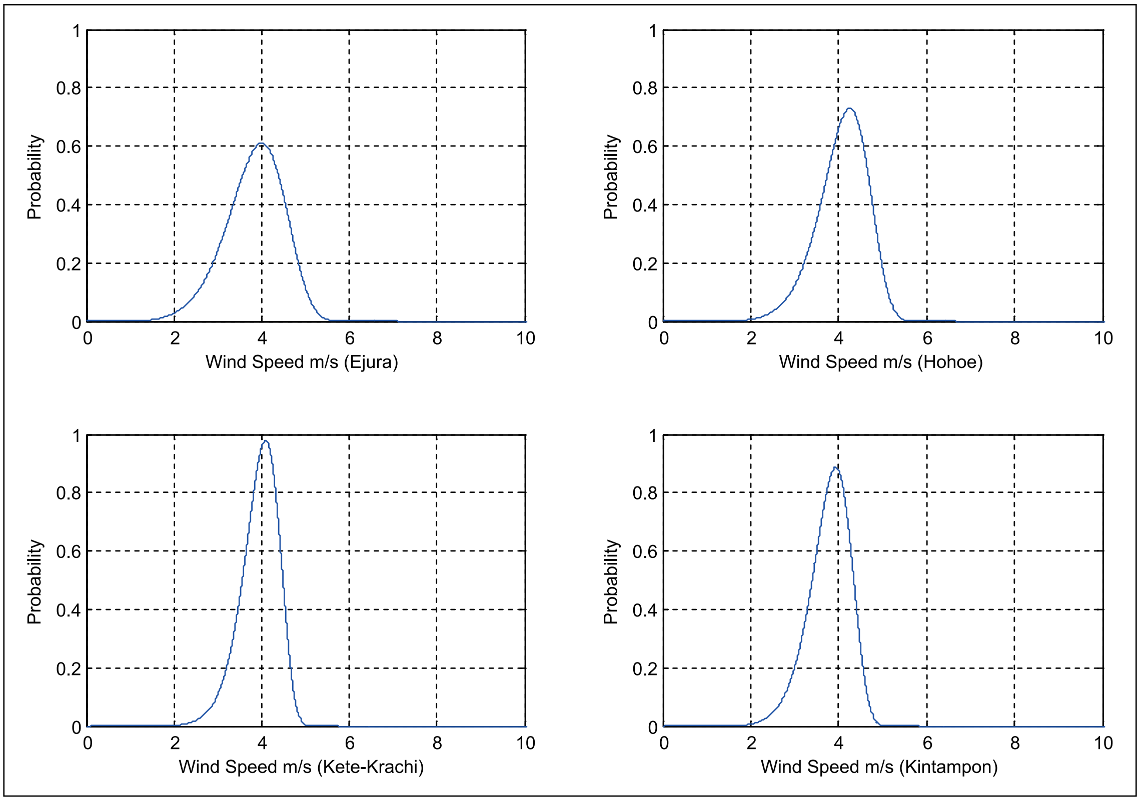


Figure 5. Probability distribution function for Ejura, Hohoe, Kete Krachi, and Kintampo.

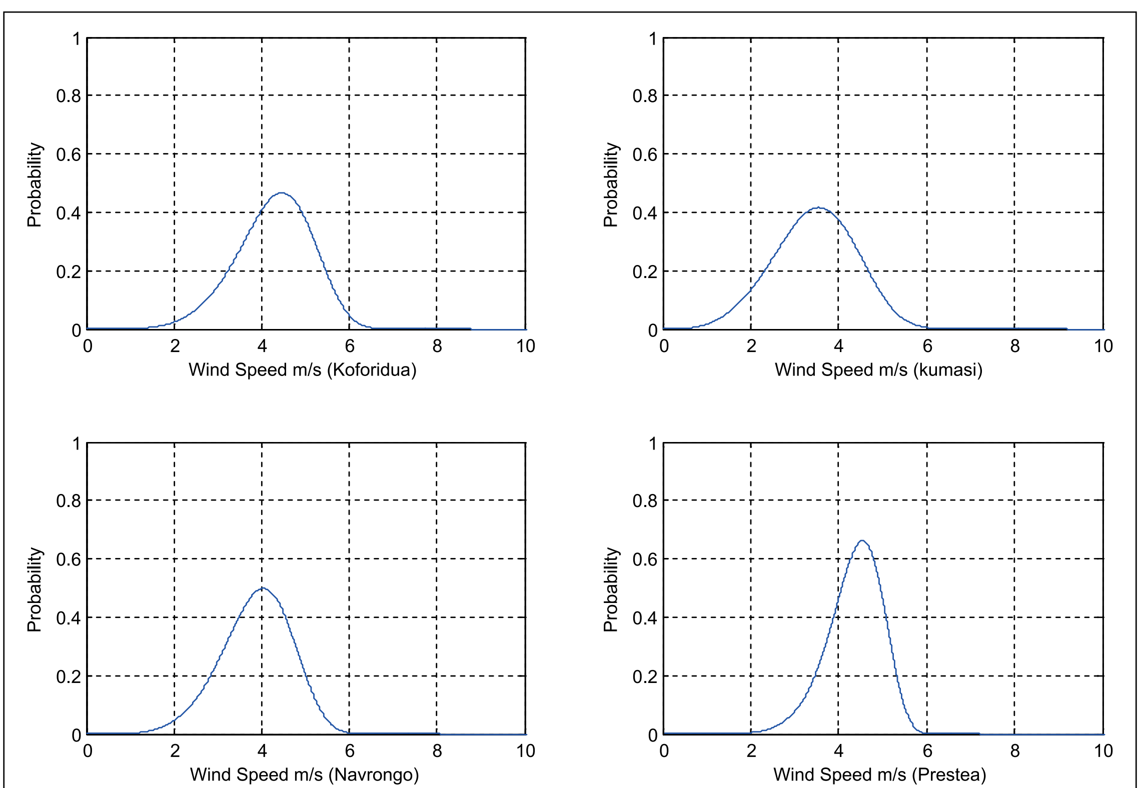


Figure 6. Probability distribution function for Koforidua, Kumasi, Navrongo, and Prestea.

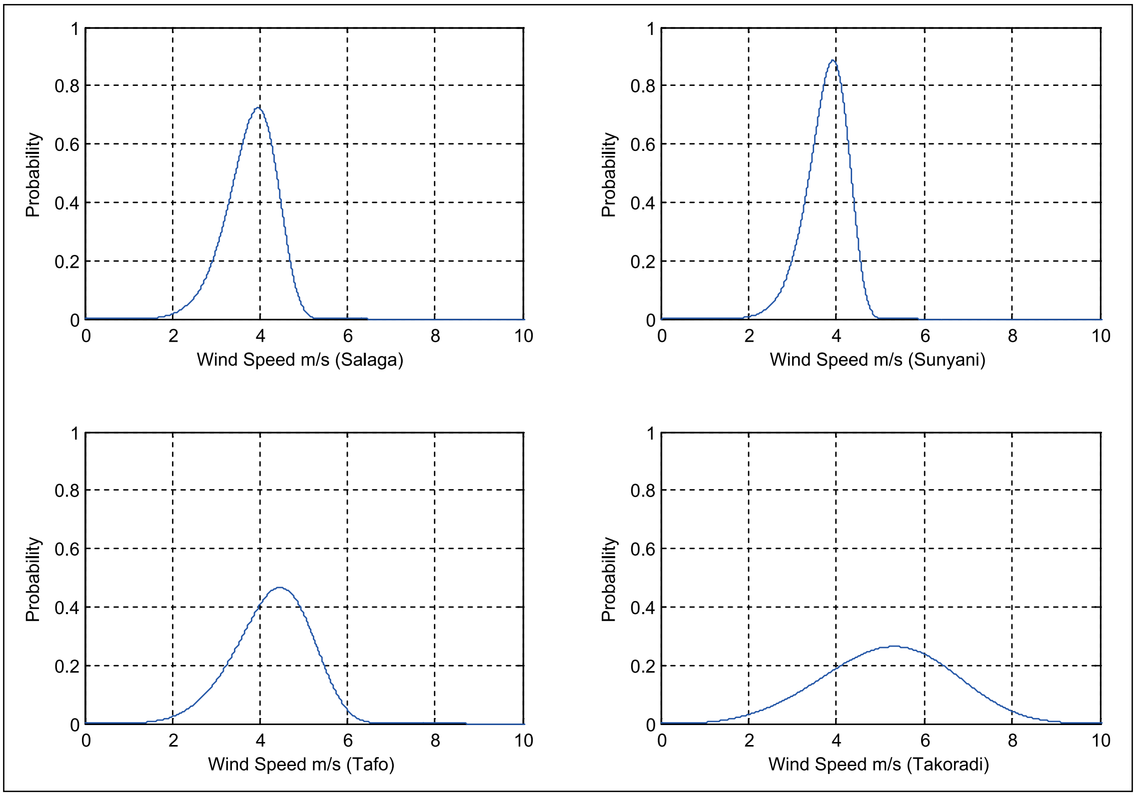


Figure 7. Probability distribution function for Salaga, Sunyani, Tafo, and Takoradi.

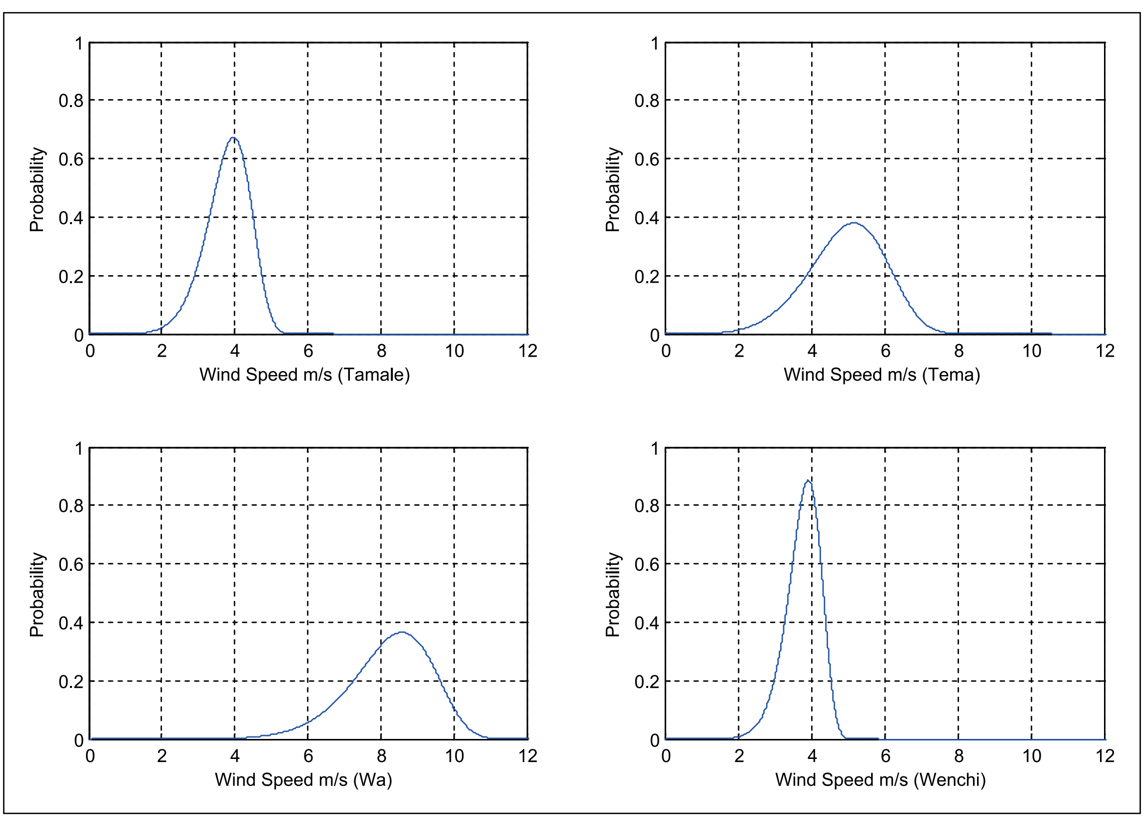


Figure 8. Probability distribution function for Tamale, Tema, Wa, and Wenchi.

Table 12. 2013 Average wind speeds for 24 locations in Ghana.

Location	Accra	Akuse	Axim	Bawku	Bibiani	Bole	Bolgatanga	Cape Coast
Average wind velocity (m/s)	5.16	4.56	5.56	3.96	3.89	3.95	3.92	4.57
Location	Ejura	Hohoe	Kete Krachi	Kintampo	Koforidua	Kumasi	Navrongo	Prestea
Average wind velocity (m/s)	3.83	4.08	3.94	3.78	4.28	3.46	3.87	4.36
Location	Salaga	Sunyani	Tafo	Takoradi	Tamale	Tema	Wa	Wenchi
Average wind velocity (m/s)	3.79	3.77	4.28	5.19	3.80	4.96	8.24	3.77

the extrapolation technique adopted with the Weibull distribution model which was equally adopted in the same way as Ayodele et al. (2012), Belu and Koracin (2013), Holt and Wang (2012), Parajuli (2004), and Şen et al. (2012). The average wind speeds collected at the 60-m height were very satisfactory and promising for potential wind power production. The average wind velocities (m/s) obtained per respective locations are presented in Table 12.

Conclusion

This article presented a vertical extrapolation of wind velocity using a Weibull distribution function for 24 locations in Ghana based on wind data velocity collected from RETScreen Plus software in the year 2013. It was observed that the lowest wind velocity in Ghana for the year 2013 was obtained at Wenchi (3.77 m/s) while the highest was obtained at Wa (8.24 m/s). The trend in the wind speed recorded also shows that the highest values were obtained during the period of July–November. The wind speed data resulting from this article may be of national interest for anyone who desires to undertake feasibility studies or real implementation of wind power plant in Ghana. These data also form part of a 5-year study on wind speed variability in Ghana for the period 2013–2018 which is still under evaluation.

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