

ESTIMATION OF WIND RESOURCES AT COMMERCIAL ALTITUDES FOR UNITED NATION SURVEYED INLAND AND COASTAL REGIONS OF BANGLADESH

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ABSTRACT

This paper provides an estimation of the wind regime of Bangladesh and compares its wind power by classifying the country into coastal and inland zones on the basis of surveys undertaken by the United Nations' (UN) Solar and Wind Energy Resource Assessment Program. A number of stations from three regions of the country are analyzed in terms of established parameters like Weibull distribution of wind data, range of wind power density, frequency distribution of wind directions, approximation of probability density functions and energy pattern factor analysis over a decade using measured data collected from Bangladesh Meteorological Department (BMD). The prediction and assessment of wind potential are performed for commercial turbine altitudes (~50 to 70m) to overcome the limitations of the weather data obtained by meteorological anemometers at lower heights. This ensures that the wind potential of the country as a whole is evaluated rather than only the coastal areas and offshore islands usually considered in literature. The prospects of harvesting wind energy are identified for the stations with their variability which will ensure a more accurate assessment of the wind potential of Bangladesh.

Keywords: DDDP Prediction Method, Wind Regime, Wind Power Density (WPD), Turbine Height.

1. INTRODUCTION

Current global trends in energy supply and consumption in developing countries like Bangladesh are inherently unsustainable – both environmentally and economically. Bangladesh produces 82% of its electricity using natural gas, the country's most abundant energy resource, but still faces a deficit in gas supply of 142 million cubic feet per day in 2011 [1]. In 1971, only 3% of the total population in Bangladesh had access to commercial electricity. Although the figure stands at 33% today this cannot be called a success story. The reason is while the current installed capacity is 5320 megawatts, because of reduced efficiency of the old generating units and system loss the effective capacity stands at only 4830 megawatts as of November 2008 [2-3]. Among the various alternate energy sectors in the world, wind generation has become the fastest growing source of renewable energy [4]. The top ten newly installed wind systems of the year 2010 suggest that the emerging economic powers are increasingly investing in this particular sector [5]. Currently wind turbines account for 5.18% of the implemented renewable energy technologies in Bangladesh [6]. In this country research for its wind potential has been done focusing on its coastal areas primarily as Bangladesh has a 724 km long

coastal line and a number of offshore islands in the Bay of Bengal [7-8]. But the United Nations Environment Programme (UNEP) has identified three potential hotspots on the Bangladeshi mainland, including the coastal belt, with potential to harvest wind energy [9]. Moreover the literature often focused on wind data obtained at a moderate height of 10~25m [7-8, 10] which is not suitable for large scale wind turbines as they need analysis of wind performance at an altitude of 50~100m. This paper compares the wind assessments of the three regions of Bangladesh in terms of established methodology like wind power density and Weibull parameters to evaluate its wind potential with the Density Distribution Direction Pattern (DDDP) prediction method. Prediction of wind regime is obtained for nine different stations from the hotspots at a practical turbine height of 50m on the basis of actual meteorological data.

2. WIND MAP OF BANGLADESH PREPARED BY UNEP

The United Nations Environment Programme (UNEP) has been running the Solar and Wind Energy Resource Assessment (SWERA) project to stimulate renewable energy development in thirteen developing countries in Latin America, the Caribbean, Africa and

Asia [9]. Figure 1 shows the wind resource map of Bangladesh produced by SWERA which defines the landmasses in terms of wind power density. The map indicates three regions of Bangladesh with wind potential (hotspots). It includes the well established coastal belt of south and southeast (region 1), the inland region of the southeast (region 2) and a second inland concentration in the north (region 3). To assess these regions data is obtained from the Bangladesh Meteorological Department (BMD) for a 10 year period (1998-2007) from stations in Cox's bazaar, Bhola, Hatiya (region 1), Barisal, Khepupara, Chandpur,

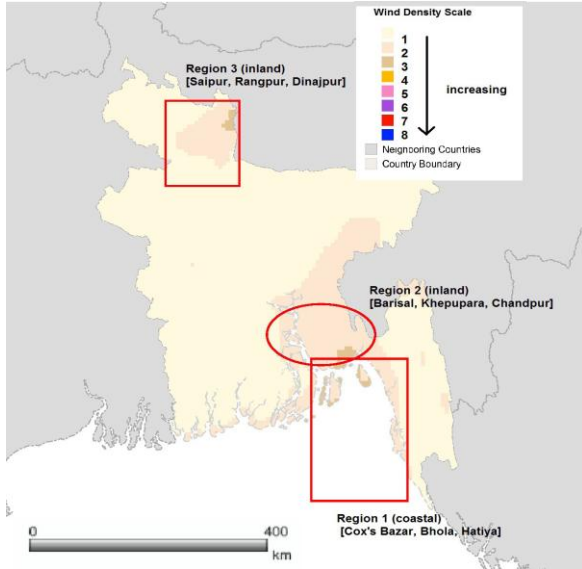


Fig 1. Wind Resource Map of Bangladesh (SWERA) showing Coastal and Inland Hotspots

Patuakhali (region 2) and Saidpur, Rangpur, Dinajpur (region 3) and the wind regime is estimated for the hotspots at a height of 50m which is explained in the following sections.

3. RESULT OF DDDP WIND REGIME ANALYSIS

3.1 Average Wind Power Density at Commercial Altitudes

The wind power density (WPD) is the standard parameter which gives an estimate of the wind potential of a site but does not depend on size, efficiency or other characteristics of wind turbines. It has units of watts/m² and depend on the density of wind and hence the height at which the density is measured. It may be given by [11]

$$WPD = \frac{1}{2n} \sum_{j=1}^n (\rho_j * V_j^3), \quad (1)$$

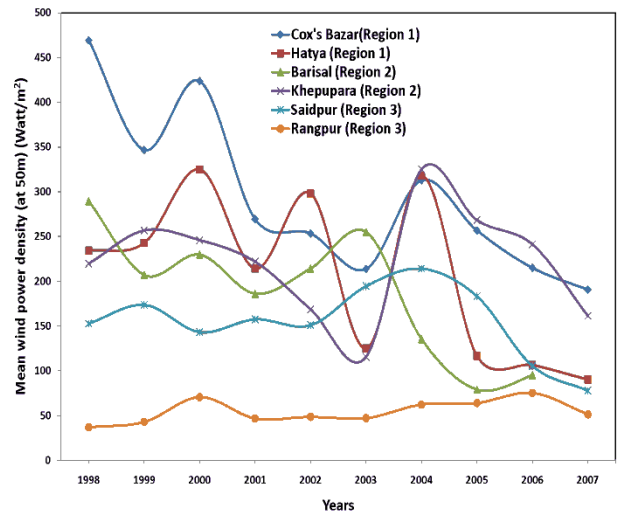


Fig 2. Mean wind power density (at 50m) of potential sites in Bangladesh

where n is the number of wind speed readings and ρ_j and V_j are readings of the air density and wind speed. Air density at sea level and under standard conditions is 1.225 kg per m³. If z is the location's elevation above sea level in meters, the approximation of wind density to account for the elevation change is given by:

$$\rho = 1.225 - (z * 1.194 \times 10^{-4}). \quad (2)$$

Assuming the density of air to be constant, the mean wind density may be calculated from

$$WPD = \frac{1}{2} \rho U^3, \quad (3)$$

where U^3 is the mean value of the third power of average wind speeds taken over a sufficiently long interval. Figure 2 presents the variation of the mean WPD over ten years where regions one and two (Cox Bazar and Khepupara) show the best density potential but with a wide degree of fluctuation.

3.2 Weibull Parameter Distribution

Actual power available in the wind depends upon the wind speed probability density function along with the statistical averages. The estimation of Weibull parameters is related with the expected wind energy production. The Weibull distribution can be expressed as [12]

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (k > 0, v > 0, c > 1). \quad (4)$$

Here v is the wind speed at the turbine height, k is the Weibull shape parameter and c is the Weibull scale parameter. The shape parameter k measures the shape of the probability distribution curve and its value can be calculated from the σ/\bar{v} curve [13]. The value of k and c are expressed by

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}, \quad (1 \leq k \leq 10) \quad (5)$$

$$c = \bar{v} / \Gamma(1 + \frac{1}{k}). \quad (6)$$

Here \bar{v} and σ stand for mean wind speed and its standard deviation respectively and $\Gamma()$ uses an approximation of the first order gamma function

$$\Gamma(1 + \frac{1}{k}) = 0.825 + 0.0135k + \exp[-(2 + 3(k - 1))]. \quad (7)$$

Figure 3 presents the relative standard deviation of a Weibull distribution as a function of Weibull shape factor in the form of the σ/\bar{v} curve plotted against the shape factor k. The yearly distribution of Weibull scale

parameter and mean WPD at 50m for the observed stations are provided in table I.

3.3 Weibull Parameters from Energy Pattern Factor

Weibull parameters can also be related to another statistical term called the energy pattern factor (KE) which is defined as the ratio of the total amount of power available in the wind to the statistical power calculated from the cube of the mean wind speeds [13]. The statistical definition of the pattern factor for N number of average wind speeds is given by

Table I: Yearly distribution of mean WPD and Weibull scale parameter (C , m/s) at 50m

Location	Cox's Bazar(Region 1)			Khepupara (Region 2)			Saidpur (Region 3)		
	Year	c (m/s)	Vmean(m/s)	WPD (W/m2)	c (m/s)	Vmean(m/s)	WPD (W/m2)	c (m/s)	Vmean(m/s)
1998	9.68	8.96	469.17	7.58	6.67	219.77	6.68	6.15	152.82
1999	8.83	8.04	346.64	7.98	7.03	256.78	6.97	6.13	173.59
2000	9.37	8.64	423.53	7.84	6.91	246.01	6.36	6.08	143.21
2001	7.97	7.49	269.47	7.41	6.43	221.89	6.71	6.23	157.41
2002	7.98	7.18	253.37	6.80	5.92	168.71	6.44	6.20	150.95
2003	7.37	6.93	213.83	6.14	5.49	115.62	7.21	6.68	194.47
2004	8.51	7.76	312.76	8.66	7.64	325.09	7.45	6.89	214.09
2005	7.99	7.28	256.62	8.15	7.24	268.33	7.15	6.38	183.20
2006	7.54	6.86	214.97	7.54	6.51	241.18	5.96	5.36	105.36
2007	6.95	6.70	190.55	6.88	6.12	161.37	5.33	4.91	77.74

$$K_E = \frac{\frac{1}{N} \sum_{j=1}^n (V_n)^3}{(\frac{1}{N} \sum_{j=1}^n V_n)^3}. \quad (8)$$

The Weibull shape parameter and subsequently the scale parameter can be related to the energy pattern factor which is also presented in figure 3. The Weibull parameters obtained from equations 5 and 6 are verified against this curve.

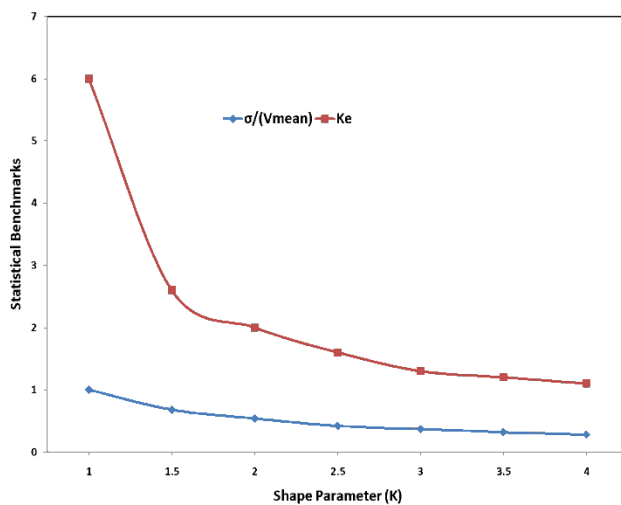


Fig 3. The σ/\bar{v} curve and the energy pattern parameter plotted against the shape factor

3.4 Frequency of Wind Directions Available in the Regions

The prominent direction of the wind flow needs to be considered for the installation of the turbines. Graphical distribution of the wind directions for the year 2007 is presented in figure 4. For the coastal belt of south and southeast (region 1) and the first inland region of the southeast (region 2), wind prominently flows from the southern direction during the summer months from March to October. Wind coverage shifts to north and northeast for the rest of the year. For the second inland concentration in the north (region 3), on the other hand,

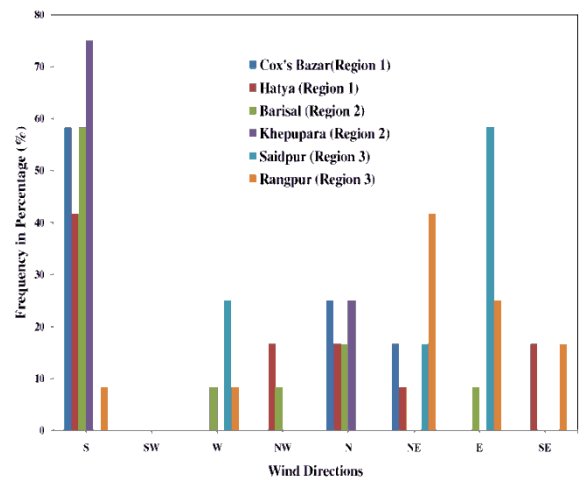


Fig 4. Distribution of Wind Directions for 2007

wind comes from the eastern direction for the summer period. If the average is taken for the whole country, wind blows from the south for about 40% of the time during a typical year whereas northern and eastern directions account for 14% and 15% respectively.

3.5 Probability Distribution of Wind Speed

To characterize the wind potential of a particular region typically three types of probability density functions (pdf) are employed [14]. The Weibull probability function for a particular wind speed is already mentioned in equation 4. It indicates the range of variability of wind speed in a particular location and the potential of the region of getting high wind gusts. The cumulative Weibull distribution function for the wind velocity v can be obtained by integrating the basic Weibull pdf as

$$F(v) = \int_0^v f(v)dv = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right]. \quad (9)$$

The probability of the wind speed being equal to or greater than a certain value V_{mes} is estimated using the following expression of the Weibull equation

$$P(v \geq v_{mes}) = \exp\left[-\left(\frac{v_{mes}}{c}\right)^k\right]. \quad (10)$$

The Weibull probability function (equation 4) for the three regions (with samples from Cox's Bazar, Khepupara, Saidpur) calculated using the anemometer wind speeds (at ~10m) and the estimated wind speeds (at 50m) are shown in figures 5 and 6 respectively. It can be seen that with increase in the turbine heights the density functions are shifted to the right, as expected. At the commercial turbine height of 50m region 2 (Khepupara) has the widest range of available wind speeds peaking at 7m/s whereas regions 1 (Cox's Bazar) and 3 (Saidpur) have higher probabilities of getting peak wind speeds of 8.5 and 6.5 m/s respectively. The representations of the third Weibull function expressed by equation 10 at the two mentioned heights are covered in figures 7 and 8. At 50m the probability of the wind speed being equal to or greater than 5 m/s is close to 100% for Cox's Bazar and around 90% for the other two regions (figure 8). During the analyzed time period, measured speeds (figure 7) higher than 5.0 m/s were observed in 90% of region 1 samples, 61% of region 2 cases and 50% of region 3 data. The probability of Anemometer speeds in excess of 7.0 m/s were recorded as 29% in the first region, 15% in region 2 cases and near 0% in the northern inland region.

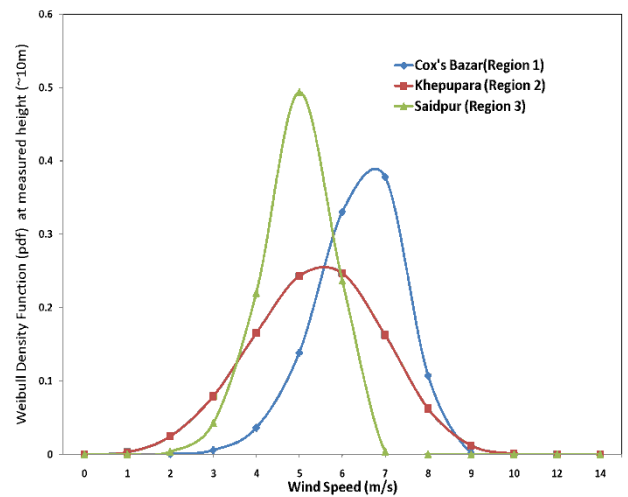


Fig 5. Weibull density functions at anemometer heights (~10m)

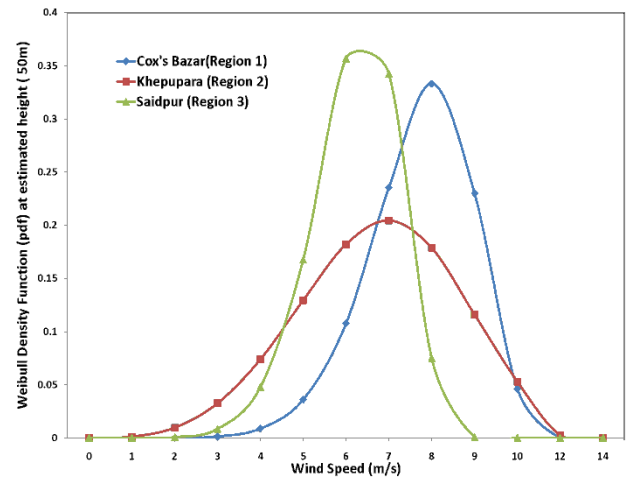


Fig 6. Weibull pdf at turbine heights (50m)

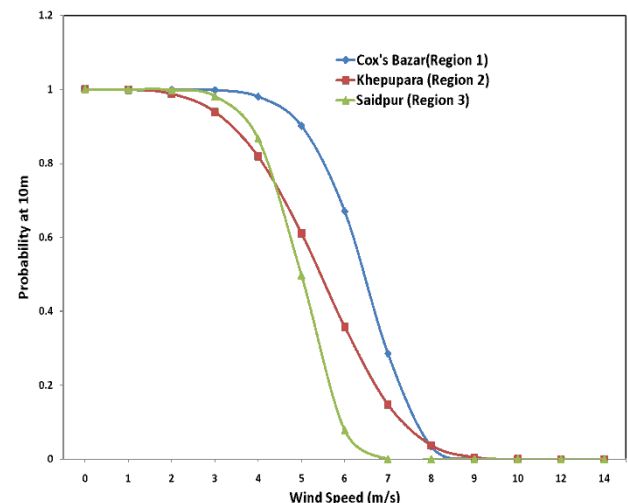


Fig 7. Probability of wind speeds exceeding necessary benchmarks at anemometer heights (~10m)

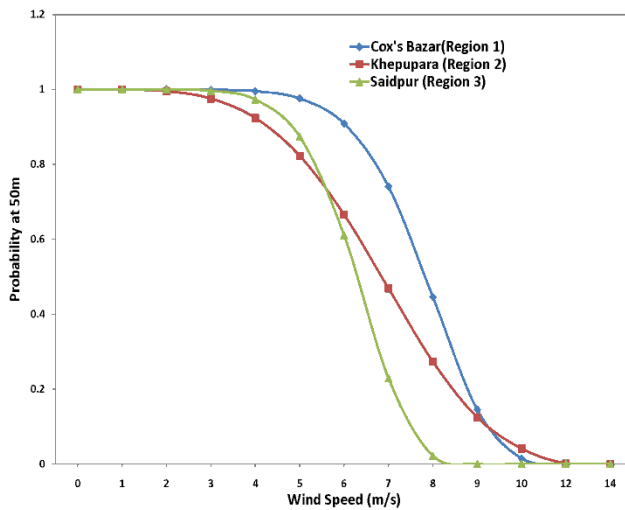


Fig 8. Turbine height (50m) probability of wind speed being equal to or greater than a certain value

3.6 Variation of Statistical Benchmarks

The yearwise calculated statistical benchmarks like the energy pattern factor (K_E) and the standard deviation

Table II: Statistical benchmarks of the three regions at 50m

Location	Cox's Bazar(Region 1)			Khepupara (Region 2)			Saidpur (Region 3)		
	K_E	σ	σ/\bar{v}	K_E	σ	σ/\bar{v}	K_E	σ	σ/\bar{v}
1998	1.07	1.41	0.16	1.21	1.82	0.27	1.08	1.02	0.17
1999	1.09	1.46	0.18	1.21	1.89	0.27	1.24	1.70	0.28
2000	1.08	1.41	0.16	1.22	1.86	0.27	1.04	0.75	0.12
2001	1.05	1.04	0.14	1.36	2.23	0.35	1.07	0.95	0.15
2002	1.12	1.47	0.21	1.33	1.96	0.33	1.04	0.73	0.12
2003	1.05	0.96	0.14	1.14	1.24	0.23	1.07	1.05	0.16
2004	1.10	1.40	0.18	1.19	2.03	0.27	1.07	1.09	0.16
2005	1.09	1.31	0.18	1.16	1.76	0.24	1.16	1.47	0.23
2006	1.09	1.26	0.18	1.43	2.52	0.39	1.12	1.12	0.21
2007	1.04	0.78	0.12	1.15	1.46	0.24	1.08	0.81	0.17

and BPDB and the Bangladesh government can look for increasing on their efforts with medium scale wind projects on the coastal and inland regions in the south and south east of the country.

5. CONCLUSIONS

An estimated scenario of Bangladesh's potential to harvest wind energy has been documented in this paper using data and predictions, following the United Nations Environment Programme (UNEP) initiated Solar and Wind Energy Resource Assessment (SWERA) project. Three different hotspots are identified in Bangladesh with regard to wind potential and prediction of wind regime is performed with the objective of assessing locations which have been unexplored up to this point. Data obtained from the national weather services are used for an observation period of ten years to ensure the consistency of the findings. Established methodology has been followed for wind regime analysis and the height of commercial wind turbines has been factored into consideration to justify the economic feasibility of the assessment. The results show the relative suitability of

to mean speed ratio (σ/\bar{v}), necessary to estimate the Weibull parameters, are documented in table II.

4. OBSERVATIONS FOR THE INLAND AND COASTAL REGIONS

The analysis and the figures of the previous section suggest that among the regions with wind potential in Bangladesh the inland zone in the southeast (Barisal, Khepupara) are suitable for small to medium scale wind projects along with the coastal belt and the offshore islands (Cox Bazar, Kutubdia, Bhola). The other region in the north show a lower potential, which may be ascribed to the location of the stations not being at the points with the highest wind gusts. For example the BMD station in the north region nearest to Kurigram, the area with highest wind density in the third hotspot, is Saidpur which is almost 100km to the southwest. It would suggest that, establishment of more meteorological stations are necessary for the north zone

nine different locations of Bangladesh in terms of Weibull density functions, probability of getting high wind gusts, frequency of directions and average wind power density and may help the evaluation of possible future national wind project sites.

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