Feasibility Study of Wind Power Generation in Bangladesh: A Statistical Study in the Perspective of Wind Power Density and Plant Capacity Factor

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Abstract- Bangladesh has a projected electricity demand of 10283 MW by the end of the year 2015. Despite having huge coastline and relatively large area only 100 MW of that huge demand is projected to come from wind power sources. Bulk of this generation is planned to be deployed in the coastal area and adjacent islands. But there are other places of interest for wind power generation, which could be a good means for solving the huge power crisis in Bangladesh. In this paper, feasibility of different scale of wind power generation in 35 different places is studied in the perspective of Wind Power Density (WPD) and Plant Capacity Factor (PCF) at different turbine heights. Only 5 of those sites attain power class 2 or more at 50m height and 17 of them are projected to achieve a PCF of 20% or greater for micro scale generation. At 120m height only 5 sites are projected to attain a much larger WPD and achieve a power class of 2 or more and remaining 30 places still belong to power class 1. Feasibility of deploying large scale wind turbine at Chittagong and Jessore, medium scale at Khepupara, and small scale at Cox's Bazar and Hatiya is studied. All 5 sites attain a PCF of 26% or more which reinforces the feasibility of deploying different scale of wind turbine at those sites.

Keywords- Bangladesh, Wind Power, Feasibility, Wind Power Density, Plant Capacity Factor, Wind Power Class

1. Introduction

By the end of the year 2015 the total demand of electricity in Bangladesh is projected to be 10283 MW [1]. According to the generation plan of Bangladesh Power Development Board (BPDB) total generation will be 11606 MW and 4366 MW of them from public sector, 5807 MW from private sector and 1433 MW from quick rental [1]. But only 107 MW of power will be generated from renewable source namely 100 MW from wind and 7 MW from solar [1]. Wind power could play a major role in solving power crisis in Bangladesh [4]. Government of Bangladesh (GOB) has recognized the importance of renewable energy in our energy planning programme and a draft Renewable Energy Policy is on the verge of being approved [2-3]. In the context of Bangladesh, renewable energy consists mainly of biomass, solar energy and wind power [2]. But there are other potential unconventional sources such as bio-diesel from mustard oil [5], which could be a useful source of energy. Bangladesh is situated between 20^0 34'-26^0 38' North Latitude and 88^0 01'-92^0 41' East Longitude [2-3]. The country has a 724 km long coast line and many small islands in the Bay of Bengal, where strong south-westerly trade wind and sea-breeze blow in the summer months and there is gentle north-easterly trade wind and land breeze in winter months [2-3]. To facilitate further actions, extensive study on wind power feasibility should be done in different parts of Bangladesh to choose the best possible options for small, medium and large scale wind power generation. Choosing wrong site would give a negative perspective for future action plan and could instigate to step aside from this very flourishing option for solving the acute power crisis in Bangladesh.

The goal of this study will be to analyze the feasibility of deploying micro, small, medium and large scale wind turbine in different parts of Bangladesh. Wind speed data for years 2002-2011 is taken into consideration for the study. The available wind speed data is taken at standard meteorological height of 10m [7]. This data is converted to 50m data by standard conversion process [6]. Monthly, yearly and overall win speed data is analyzed at 50m height. From this wind speed data wind power density [8] is calculated at different parts to categorize them into different power classes [9]. From this power classes categorization they are differentiated among different scales of generation e.g.-micro, small, medium and large scale. After obtaining the maximum feasible scale of generation in terms of wind power density possible monthly, yearly and average output power is calculated from the wind speed data by MATLAB wind turbine model. Monthly, yearly and average plant capacity factor (PCF) is calculated from this generated output power [10]. Sites having plant capacity factor (PCF) greater than 20% is assumed to be economically viable [10].

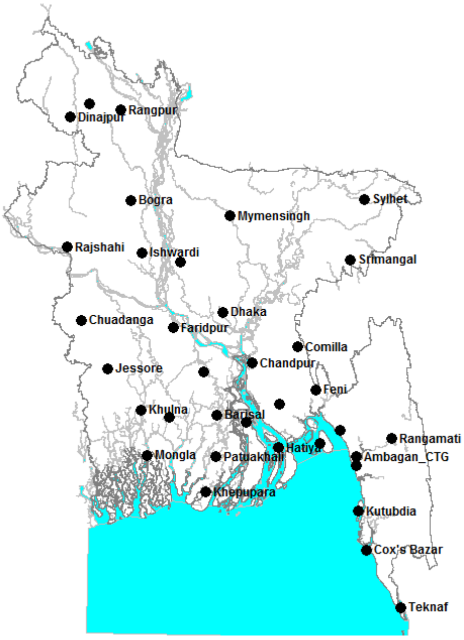

Fig. 1. Locations of different sites in different parts of Bangladesh.

Three hourly wind speed data for 35 different places of Bangladesh for the year 2002 to 2011 is available from Climate Division of Bangladesh Meteorological Department. These 35 places located at different parts of the country. Although most of the places are located on the coastal area but there are places on the other parts of the country as well. The whole country is divided into 7 administrative divisions. Every division has at least 2 sample places for the study. To be more detailed, Barisal has 4, Chittagong has 13 as it is largely located in the coastal area, Dhaka has 5, Khulna has 5 Rajshahi has 3, Rangpur has 3 and Sylhet has 2 places under consideration for this study. Figure 1 shows the relative locations of the different places under consideration for this study. It is clear from above figure 1 that almost all parts of the country are covered although coastal area has more sample places than the remainder part of the country.

2. Methods of Characteristic Assessment

The three hourly wind speed data is analyzed in terms of availability, average monthly, yearly and overall average wind speed [11]. From these samples wind power density of the different places are calculated at 50m and 120m height [6]. Then they are categorized into different power classes [9]. Based on these power classes different scales of generation are assigned to different places. All the power classes have different mean wind speed. These mean wind speeds are considered as the base speeds for different wind turbines suitable for different places [12]. Generation of power from the selected wind turbines at different sample wind speeds are calculated by MATLAB using the generic wind turbine model. Plant capacity factor (PCF) is calculated from these generated output power [11].

Availability of Wind

Wind doesn't always blow in a given place; hence wind is not always available for wind turbine to generate power [15]. Besides, availability of wind in different places is not same. Availability of wind in different moths of a year is also different [14]. Three hourly wind speed data is taken from 2002 to 2011. Lots of those samples read zero as wind is not always available. Wind availability is calculated from the below equation:

$$\mathrm{WindAvailability}(\%) = \frac{\mathrm{NumberofSamplesforwhichwindwereavailable}}{\mathrm{Numberofsamplestaken}} \times 100 \qquad (1)$$

Wind Speed

Wind speed plays a major role in selecting the turbine in a certain place. The size of the turbine is directly related to the mean wind speed [12]. The wind speed is not same at different altitude from the sea level. Usually wind speed increases at higher altitude. Three hourly wind speed data is available at standard meteorological height of 10m. There are different model for predicting the wind speed at a higher altitude. This wind speed data at 10m height is converted to a higher altitude data by the following equation [6]:

$$\frac{V_z}{V_{ref}} = \left(\frac{h}{h_{ref}}\right)^{\alpha} \qquad (2)$$

where V_z = average wind velocity at height h meter (m/s), V_{ref} = average wind velocity at reference height meter (m/s), h = the height where the velocity of wind is to be calculated (m), h_{ref} = reference height (m), α = dimensional constant that varies from 0.1 to 0.4 depending on the nature of the terrain.

Topographically (Figure 2) Bangladesh may be divided into alluvial plains and hilly areas. More than 90 percent of the total area of Bangladesh is low land, an alluvial plain formed by the sediments of the several great rivers and their tributaries and distributaries which traverse the country. There are, however, some local variations in the nature and extent of the plain land.

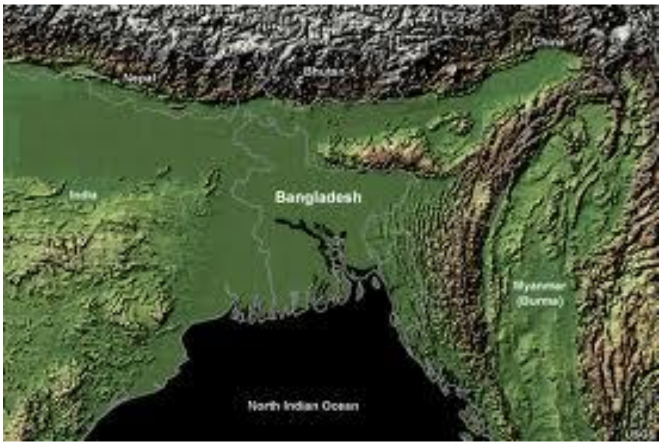

Fig.2. Orography of Bangladesh

Low hills are found in the north-eastern extremities of Bangladesh, east of Comilla. These are part or extension of the Khasia-Garo-Jainta and the Tippera Hills of India. But the more important hilly areas are concentrated in the Chittagong hill districts which are geologically the offshoots of the Arakan Yoma running through Eastern India to Burma. The Chittagong Hills are steep sloped parallel ranges, largely covered with tropical forests. These Hills rise steeply to narrow ridge lines, generally no wider than 120 feet and no higher than 2000 to 3000 feet. The highest hill in Bangladesh is Keokradang (4,034 feet) in the south-east end of Bandarban district.

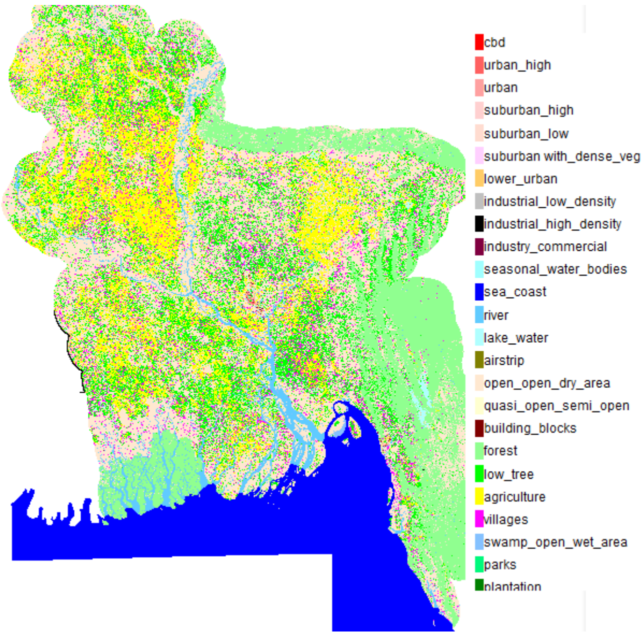

Fig.3. Topography of Bangladesh

Besides, topography (Figure 3) and vegetation (Figure 4) is almost identical throughout the country. From all these data it could be concluded that the terrain of Bangladesh is identical throughout the country.

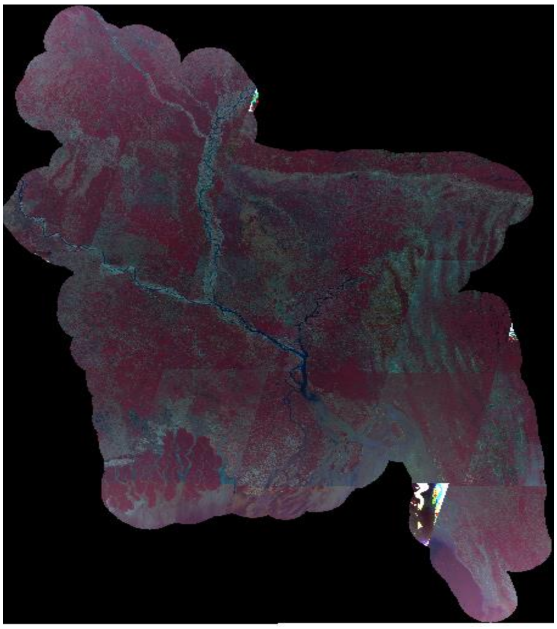

Fig.4. Vegetation of Bangladesh

For predicting the wind speed ate different places the height h is considered 50m, h_{ref} is considered 10m. α is measured 0.35 [6] in few of the previous work on this. For simplicity we shall consider the value 0.35 throughout the country.

From the 10 years wind speed data at the average wind speed at 50m height is calculated by the following equation [16]:

$$\text{Average Wind Speed}\left(\frac{\text{m}}{\text{s}}\right) = \frac{\sum \text{Wind Speed}\left(\frac{\text{m}}{\text{s}}\right)}{\text{Number of Samples Taken}} \quad (3)$$

Wind Power Density and Power Class

Wind power density is a useful way to evaluate the wind resources available at a potential site. The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine. The equation for determining the wind power density is [8-9]:

$$\text{WPD} = \frac{1}{2}\rho v^3 \quad (4)$$

where WPD= Wind Power Density, v= Wind Speed (m/s), ρ= Air Density (kg/m^3),

And that air density can be determined to varying degrees of accuracy with the following methods:

$$\rho = 1.225 - 1.194^{-4}\text{H} \quad (5)$$

where H= height in m, ρ = 1.225 kg/m3 (constant value based on U.S. Std. Atmosphere, at sea level)

For more than 1 sample the wind power density is calculated by the following equation [8-9]:

$$\mathrm{WPD} = \frac{1}{2n}\sum_{j=1}^{n} \rho_j v_j^{3} \quad (6)$$

where n is the number of wind speed readings and ρ_j and v_j are the jth (1st, 2nd, 3rd, etc.) readings of the air density and wind speed.

Power Generation

The output power of the turbine is given by the following equation [21].

$$P_m = C_p(\lambda,\beta)\frac{\rho A}{2}V_{wind}^{3} \quad (7)$$

where P_m =Mechanical output power of the turbine (W), C_p =Performance coefficient of the turbine, ρ=Air density (kg/m^3), A=Turbine swept area (m^2), V_{wind}=Wind speed (m/s), λ=Tip speed ratio of the rotor blade tip speed to wind speed, β=Blade pitch angle (deg)

Equation (8) can be normalized. In the per unit (pu) system we have [21]:

$$P_{m\_pu} = K_p C_{p\_pu} V_{wind\_pu}^{3} \quad (8)$$

where P_{m_pu} is Power in per unit of nominal power for particular values of ρ and *A*; C_{p_pu} is Performance coefficient in pu of the maximum value of C_p and V_{wind_pu} is Wind speed in pu of the base wind speed. The base wind speed is the mean value of the expected wind speed in m/s, K_p= Power gain for C_{p_pu}= 1 pu and C_{wind_pu}= 1 pu, $k_p$is less than or equal to 1.

Using MATLAB output power for every sample is calculated at 50m and 120m height. From the calculated output power plant capacity factor for every place is calculated.

3. Results and Discussion

Availability of Wind

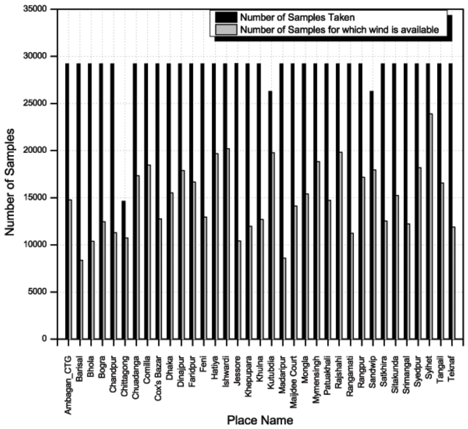

Fig. 5. Number of samples taken and number of samples for which wind is available

From figure 5, it appears that Chittagong has the lowest number of samples with 14608, Jessore has highest number of samples with 29247, Kutubdia and Sandwip have 26296 and rest of the places have 29216 numbers of samples. Sylhet has the highest number of samples with 23903 for which wind were available, Barisal is the lowest with 8369 and rest of them fall between these limits. It staggering to see that despite being a coastal city Barisal gives such poor wind availability. Chittagong doesn't have the samples for the year 2003 to 2007.

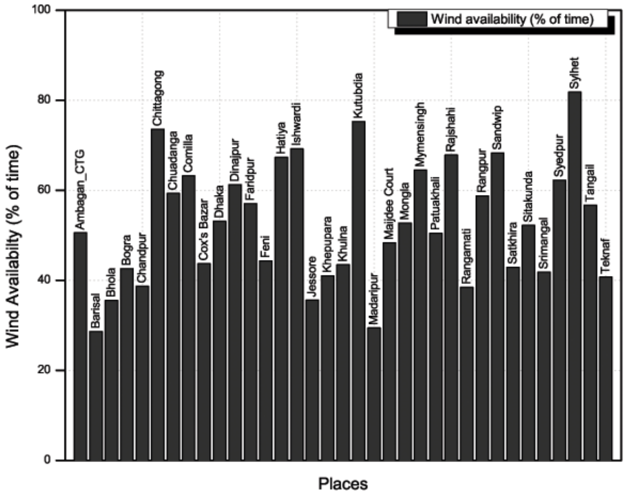

Fig. 6. Average Wind Availability

Figure 3 shows the percentage of samples for which wind was available. Sylhet has the highest percentage of wind availability with 82%, Kutubdia and Chittagong follow shortly with 75% and 74% respectively. Barisal and Madaripur have the lowest availability with only 29%.Rest of the places fall between these limits.

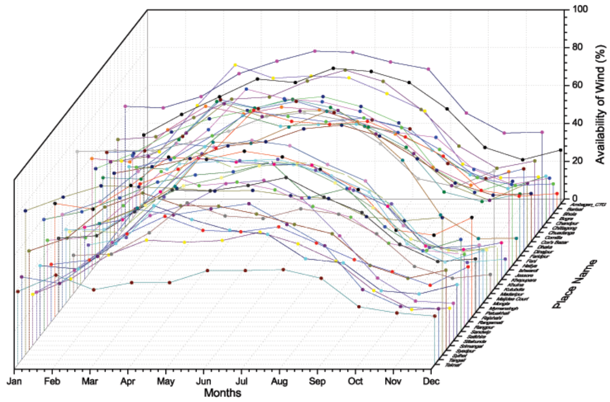

Fig. 7. Average Monthly Wind Availability Distribution

Figure 7 shows the monthly wind availability trends for different places. During the middle of the year wind availability is very high. But towards the end of the year and at the beginning of the year wind availability tend to decrease. It rises as high as 93% for the month of June and July for Chittagong and Kutubdia; fall as low as 6% for Jessore in the month of November. Even Chittagong which has a large average availability of 75% experiences a modest wind availability of 50% during November.

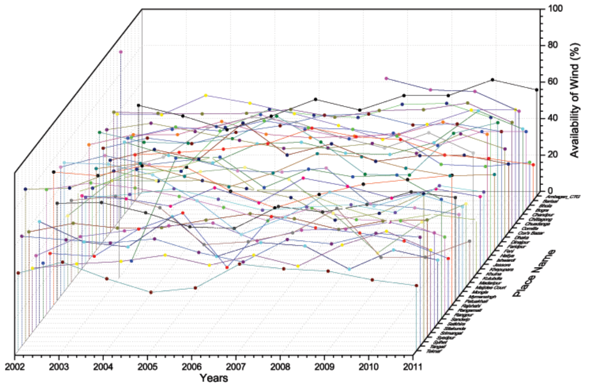

Fig. 8. Average Yearly Wind Availability

Figure 8 shows a yearly wind availability trend for the year 2002 to 2011. Wind availability trends remain almost constant for the specified timeline. The average wind availability was 52% for the given time. In the year 2005 it increased to a higher value of 56% and in the year 2009 it decreased to a lower value of 49%. In the year 2010 it increased once again, but decreased in the following year. The maximum wind availability for a place was 93% for Sylhet in the year 2005, but a lot of dips and bums have been seen ever since. The minimum wind availability was 14% Madaripur in the year 2009 and 20010. From above discussion it is clear that wind availability varies during the year at different places but wind availability over the different years remains almost constant.

Wind Speed

Chittagong shows a moderate average wind speed of 4.60 m/s, but rest of the places have a very low average wind speed. The next highest wind speed is 2.73 m/s at Sylhet. Only 9 places have average wind speed over 2 m/s, 13 places have average wind speed between 1 m/s to 2 m/s and remaining 13 places have a very low wind speed of less than 1 m/s. The worst of all is at Madaripur with a modest speed of 0.66 m/s. These informations clearly appear in figure 9.

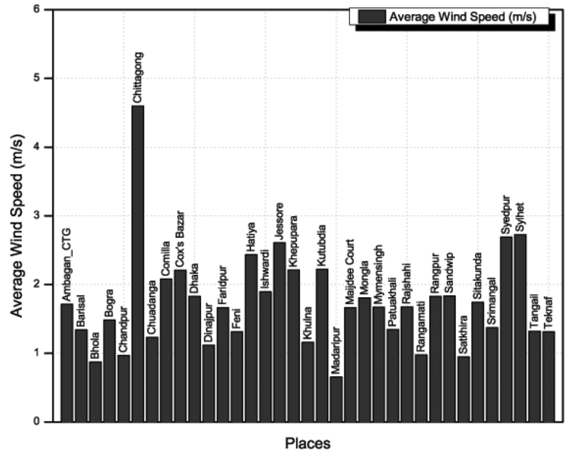

Fig. 9. Average Wind Speed

Wind speed spectrum is a good measure of repetitive occurrence of different wind speed at different time. The ideal wind speed spectrum should be a Gaussian distribution around the mean wind speed [17].

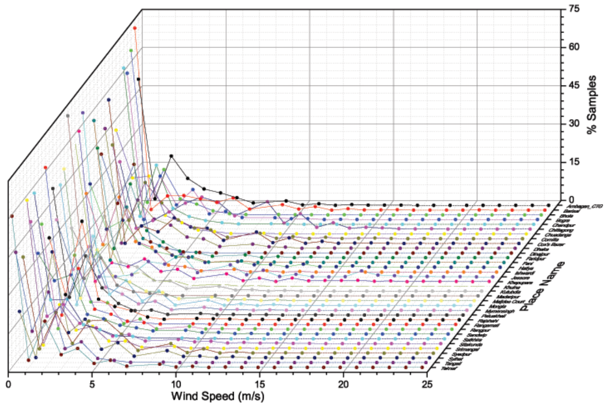

Fig. 10. Wind Speed Spectrum

Figure 10 shows the wind speed distribution of all 35 places. All the distribution curves are skewed towards the zero. 48% of the overall samples remain zero, 50% samples fall between 1 m/s to 10 m/s and remaining 2% fall outside the mentioned range.

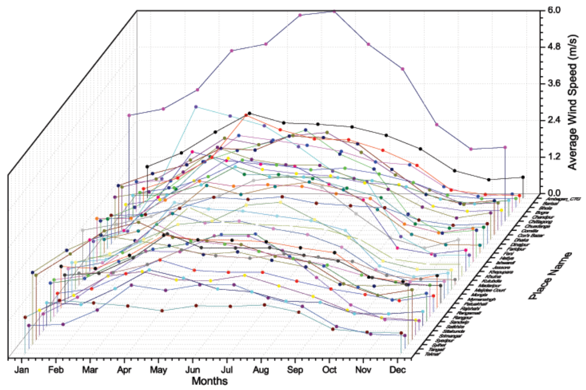

Fig. 11. Average Monthly Wind Speed

Figure 11 shows the monthly average wind speed trend at all 35 places. During the middle of the year wind speed is at its greatest value, towards the end of the year and at the beginning of the year the wind speed ceases markedly. Chittagong has the highest average wind speed among all of them in the month of July at 6.88 m/s. Rest of them are closely stacked together.

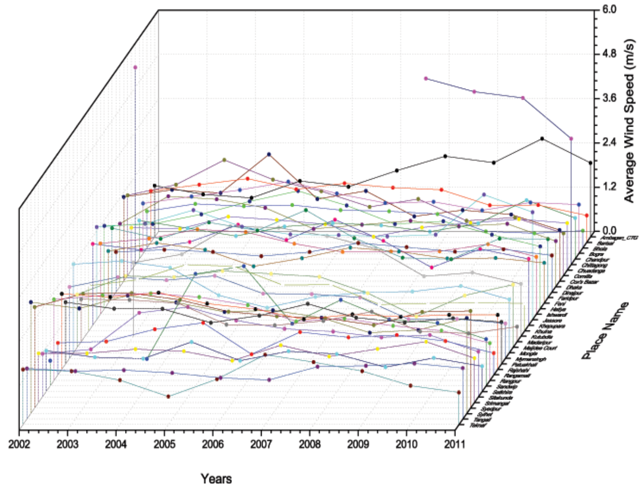

Fig. 12. Average Yearly Wind Speed

Yearly average wind speed almost remains constant (Figure 12). From the year 2002 to 2008 it was very closely spaced together. 2005 has seen the greatest average wind speed at 1.85 m/s. But towards the end of the decade the average wind speed has reduced drastically. The average wind speed in the year 2011 was a modest 1.35 m/s which is significantly lower than the preceding years.

Wind Power Density and Power Class

Wind power density is calculated at 50m height for all 35 places and plotted in the Figure 10:

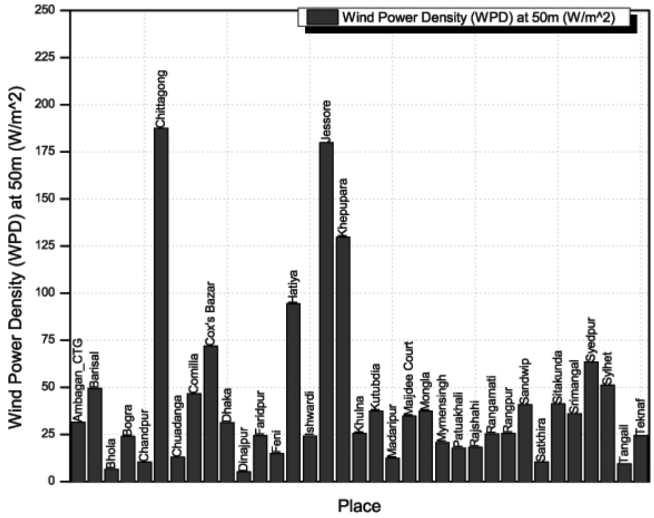

Fig. 13. Wind Power Density (WPD) at 50m (W/m^2)

Chittagong has the highest wind power density with 187 W/m3 (Figure 13), shortly followed by Jessore with 180 W/m3 and Khepupara with 130 W/m3. Rest of the places has wind power density less than 100 W/m3. From this wind power density all this sites can be divided into different power classes. There are 7 different power classes e.g.-1-7. Table 1 shows the relationship between power classes and wind power density.

From calculated wind power density and table 1 it is seen that all 35 places fall in power class 1 at 50m height. As we know that wind speed increase with the increase of turbine height, wind power density will also increase with the increase of the height. Commercial wind turbines operate between 30m to 120m height [20]. Hence wind power density is calculated at different height and plotted in the figure 11. Form the newly calculated wind power density power classes of different sites are measured at 120m.

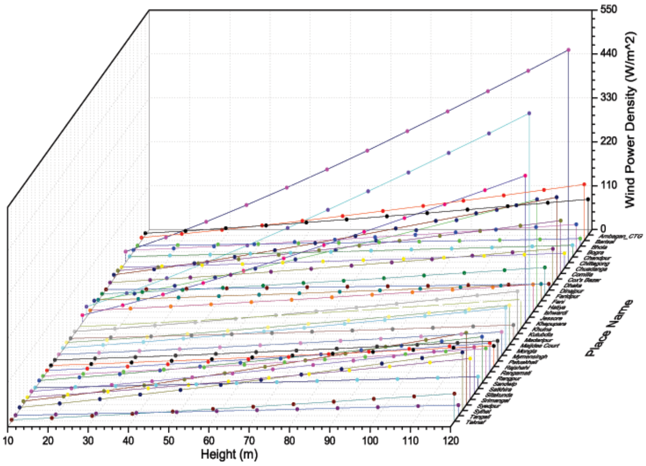

Fig. 14. Wind Power Density at Different Height (m)

As expected, wind power density has increased [20] with the height as per figure 11. From the calculated wind power density and table 1 it is seen that Chittagong and Jessore fall in power class 5, Khepupara in class 3, Cox's Bazar and Hatiya in class 2 and rest of the places in power class 1 at 120m height. Other 30 places fall into power class 1. Although power class cannot directly relate to the scale of the power generation but for economic reason low power class sites are not used for high scale power generation [11]. Usually power class 5 or more are used for large scale power generation. In some cases class 4 sites can also be used for large scale generation. In that case plant capacity factor will be reduced. Below table summarize the general relation between power class and scale of generation [11]. From table 2 it is seen that difference among different scale of generation is rotor diameter and mean wind speed. Larger the scale of generation larger the rotor diameter and mean wind speed [18]. At 50m height maximum scale of generation is micro scale for all 35 places. Because wind power density for all sites is less than 200 W/m2 and power class is 1 for all the sites. At 120m height large scale generation is possible at Chittagong and Jessore, medium scale at Khepupara and small scale at Cox's Bazar and Hatiya. But rest 30 places still remain suitable for micro scale generation.

Table 1. Wind Power Class [8-9]

Wind Power Class	At 10 m (33 ft)		At 50 m (164 ft)	
	Wind Power Density (W/m^2)	Mean Speed Range (b) m/s(mph)	Wind Power Density (W/m^2)	Mean Speed Range (b) m/s(mph)
1	<100	<4.4 (9.8)	<200	<5.6(12.5)
2	100-150	4.4 (9.8)/5.1 (11.5)	200-300	5.6 (12.5)/6.4 (14)
3	150-200	5.1 (11.5)/5.6 (12.5)	300-400	6.4 (14.3)/7.0 (15)
4	200-250	5.6 (12.5)/6.0 (13.4)	400-500	7.0 (15.7)/7.5 (16
5	250-300	(13.4)/6.4 (14.3)	500-600	7.5 (16.8)/8.0 (17)
6	300-400	6.4 (14.3)/7.0 (15.7)	600-700	8.0 (17.9)/8.8 (19)
7	7 >400	>7.0 (15.7)	>800	>8.8 (19.7)

Table 2. Classification of different generation scale (Source: Spera, 1994 and Gipe, 1999)

Scale	Rotor Diameter	Power rating	Power Class	Mean Wind Speed (m/s)
Micro Scale	Less than 3m	50 W to 2 kW	1	Less than 5.6
Small Scale	3m to 12m	2 kW to 40 kW	2	5.6 to 6.4
Medium Scale	12m to 45m	40 kW to 1 MW	3,4	6.4 to 7.5
Large Scale	More than 45m	More than 1 MW	5,6,7	More than 7.5

Table 3. Power Class and maximum scale of generation at 50m and 120m Height

	Wind Power Density (W/m^2)		Power Class		Feasibility	
Place Name	At 50m	At 120m	At 50m	At 120m	At 50m	At 120m
Ambagan_CTG	32	90	1	1	Micro Scale	Micro Scale
Barisal	49	141	1	1	Micro Scale	Micro Scale
Bhola	7	18	1	1	Micro Scale	Micro Scale
Bogra	24	68	1	1	Micro Scale	Micro Scale
Chandpur	10	30	1	1	Micro Scale	Micro Scale
Chittagong	187	532	1	5	Micro Scale	Large Scale
Chuadanga	13	37	1	1	Micro Scale	Micro Scale
Comilla	47	132	1	1	Micro Scale	Micro Scale
Cox's Bazar	72	204	1	2	Micro Scale	Small Scale
Dhaka	31	89	1	1	Micro Scale	Micro Scale
Dinajpur	5	15	1	1	Micro Scale	Micro Scale
Faridpur	24	70	1	1	Micro Scale	Micro Scale
Feni	15	42	1	1	Micro Scale	Micro Scale
Hatiya	94	268	1	2	Micro Scale	Small Scale
Ishwardi	24	68	1	1	Micro Scale	Micro Scale
Jessore	180	511	1	5	Micro Scale	Large Scale
Khepupara	130	368	1	3	Micro Scale	Medium Scale
Khulna	26	72	1	1	Micro Scale	Micro Scale
Kutubdia	37	106	1	1	Micro Scale	Micro Scale
Madaripur	12	35	1	1	Micro Scale	Micro Scale
Maijdee Court	35	98	1	1	Micro Scale	Micro Scale
Mongla	37	106	1	1	Micro Scale	Micro Scale
Mymensingh	21	59	1	1	Micro Scale	Micro Scale
Patuakhali	18	50	1	1	Micro Scale	Micro Scale
Rajshahi	18	52	1	1	Micro Scale	Micro Scale
Rangamati	25	72	1	1	Micro Scale	Micro Scale
Rangpur	26	73	1	1	Micro Scale	Micro Scale
Sandwip	41	116	1	1	Micro Scale	Micro Scale
Satkhira	10	30	1	1	Micro Scale	Micro Scale
Sitakunda	41	117	1	1	Micro Scale	Micro Scale
Srimangal	36	102	1	1	Micro Scale	Micro Scale
Syedpur	64	180	1	1	Micro Scale	Micro Scale
Sylhet	51	145	1	1	Micro Scale	Micro Scale
Tangail	9	27	1	1	Micro Scale	Micro Scale
Teknaf	24	69	1	1	Micro Scale	Micro Scale

Power Generation

At 50m maximum micro scale generation is considered at every site. At 120m apart from Chittagong, Jessore, Khepupara, Cox’s Bazar and Hatiya all other places are not included in the analysis as at that height all those places still suitable for only a micro scale generation. At 120m micro scale generation wouldn’t be economical.

Power Generation at 50m height

For power class 1 small, medium and large scale generation is not possible as mean wind speed is very low. But there are specially designed micro scale wind turbines which work in a very small wind of 0.25 m/s [22]. The base wind speed for these turbines is 4.64 m/s and cut out wind speed is 20 m/s [22]. Figure 16 shows a wind speed vs output power curve based on the relation between Cp and λ (Figure 15).

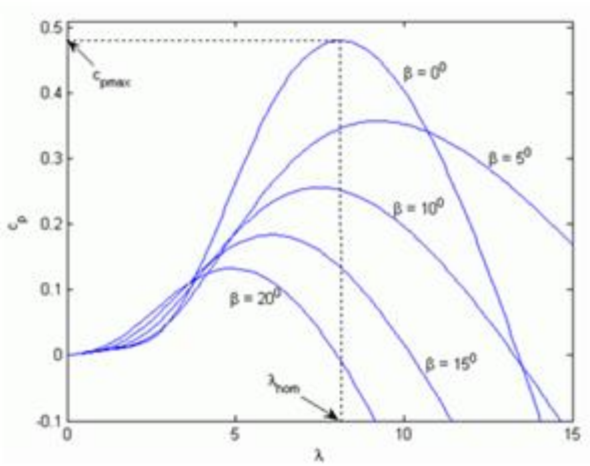

Fig. 15. Relation between Cp and λ

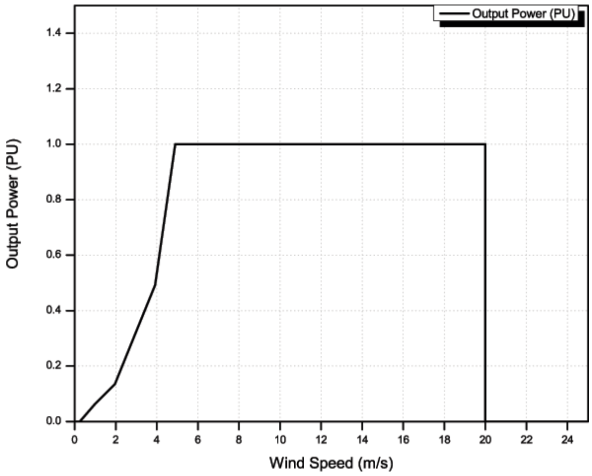

Fig 16. Output Power Curve at different speed for micro scale wind turbine.

The figure shows that the cut in and cut out wind speed is 0.25 m/s and 20 m/s respectively. It means these turbines will produce output power in the wind speed range of 0.25 m/s to 20 m/s [22]. The base speed of 4.64 m/s means it will produce rated output power if wind speed is 4.64 m/s or better. Any wind speed less than 4.64 m/s will produce a scaled down output power [22].

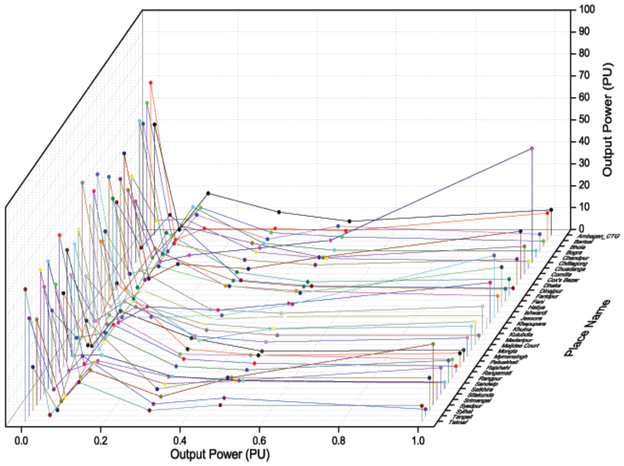

Fig. 17. Power spectrum at 50m

Generated power for every sample is calculated by MATLAB and frequency of a certain output power is plotted in the figure 17 for all 35 places. Most of the samples are zero or close to zero. 49% of the total samples produce zero output power. Only 10% of the total samples produce rated output power. Remaining of the samples produce power in between zero and rated output power. Monthly capacity factors trends in the figure 18 show that April month has the highest average capacity factor at 32%, followed by May, June and July with 29%. November sees the lowest capacity factor with 7%, followed by December at 8%. Things improve a bit in January and February with 12% and 15% capacity factors respectively. From March to September it remains steady in the range of 20% to 32%. In the month of October it begins to reduce at a very small value of 11%.

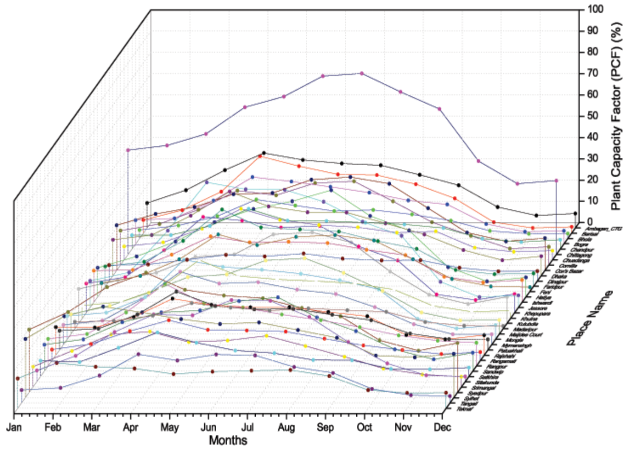

Fig. 18. Average monthly plant capacity factor (PCF) at 50m

Chittagong has a good PCF in the range of 33% to 85% throughout the year; July has the highest PCF with 85% and November has the lowest with 33%. Overall Madaripur has the lowest PCF with 6% and a mere 1% PCF is observed in the month of November and December.

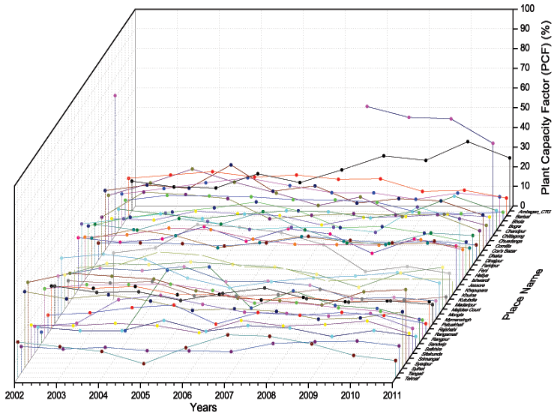

Fig. 19. Average Yearly PCF trend at 50m

Over the year the PCF remains almost constant as shown in the figure 19. From the year 2002 to 2008 PCF was almost constant in the range of 19% to 22%. But from the year 2009 it has started declining and reduced to a small value of 15% in the year 2011. With 22% of PCF year 204 and 2005 had the highest PCF. Year 2009 and 2010 had a PCF of 17% and 18% respectively. As expected, Chittagong had the highest PCF in the year 2002. From the year 203 to 2007 wind speed data of Chittagong was not available. But from the year of 2008 to 2011 PCF is on a continuous decline and has reduced to 47%.

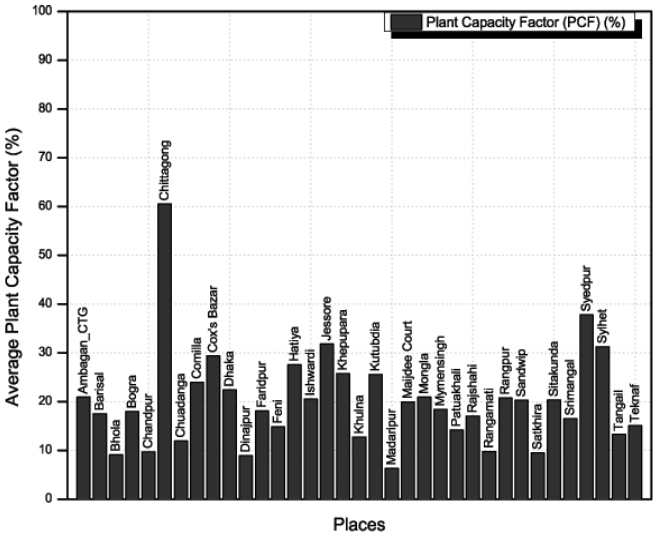

Fig. 20. Average PCF at 50m

In Figure 20 Chittagong has the highest average PCF over the period with 61%, Syedpur is very far behind at second with 38%. Only 15 sites of the remaining 33 have a PCF over 20%, rest of the 18 have a small PCF of less than 20%.

Power Generation at 120m height

Out of 35 sites only 5 sites are suitable for small, medium and large scale generation at 120m height; rest 30 sites are still in power class 1 and suitable for maximum micro scale generation. Hence at 120m height only these 5 sites are considered for analysis and rest 30 sites are not included in the analysis.

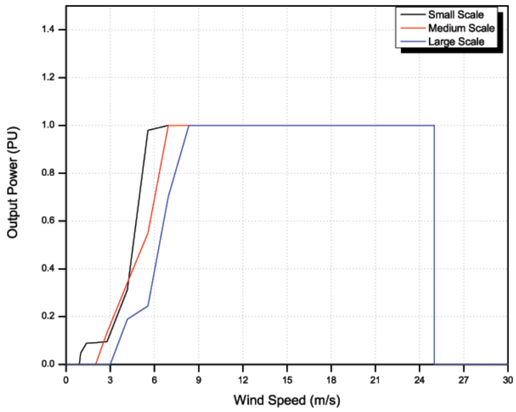

Fig. 21. Output Power Curve at different speed for small, medium and large scale wind turbine.

For small, medium and large scale generation cut in wind speed is considered 1 m/s, 2m/s and 3m/s respectively [11]. Cut out speed remains same at 25 m/s for every site. The mean wind speed of every power class is taken as the base wind speed. The base wind speed is 5.6m/s, 6.4 m/s and 7.5m/s for small, medium and large scale generation respectively (Figure 21).

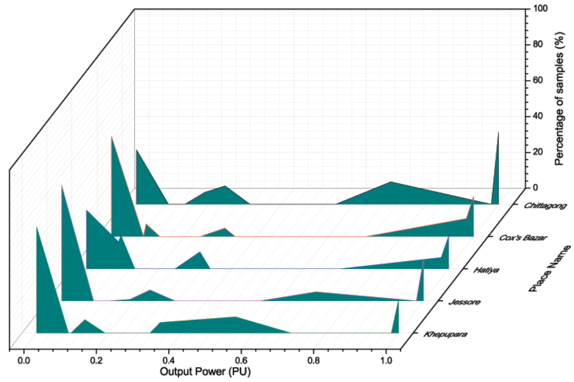

Fig. 22. Power spectrum at 120m

The power spectrum (Fıgure 22) shows that output power for a big portion of the samples remain zero or close to zero. 52% of the overall samples remain zero, but 22% of the samples produce rated output power, which is a significant improvement from 50m height. Rest of the 28% samples produce power but fail to deliver a rated output.

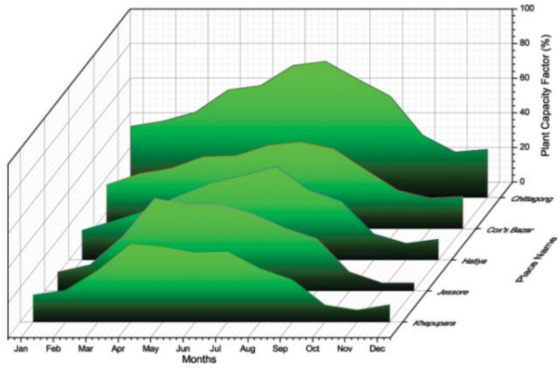

Fig. 23. Average monthly plant capacity factor (PCF) at 120m

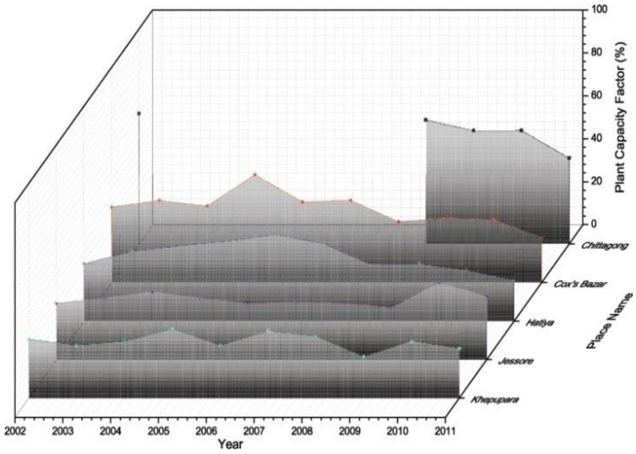

Fig. 24. Average Yearly PCF trend at 120m

Monthly capacity factors trends in the figure 23 show that July has the highest average capacity factor at 54%, followed by June with 53%. November sees the lowest capacity factor with 13%, followed by December at 15%. Things improve a bit in January and February with 22% and 26% capacity factors respectively. From April to September it remains steady in the range of 36% to 54%. In the month of October it begins to reduce at a very small value of 19%. Chittagong has a good PCF in the range of 26% to 79%

throughout the year; July has the highest PCF with 79% and November has the lowest with 26%. Overall Madaripur has the lowest PCF with 28%.

Over the year the PCF remains almost constant as shown in the figure 16. From the year 2002 to 2007 it has ascended continuously. Dipped a little in the year 2009, increased in the year 2010 and again decrease in 2011 (Figure 24).

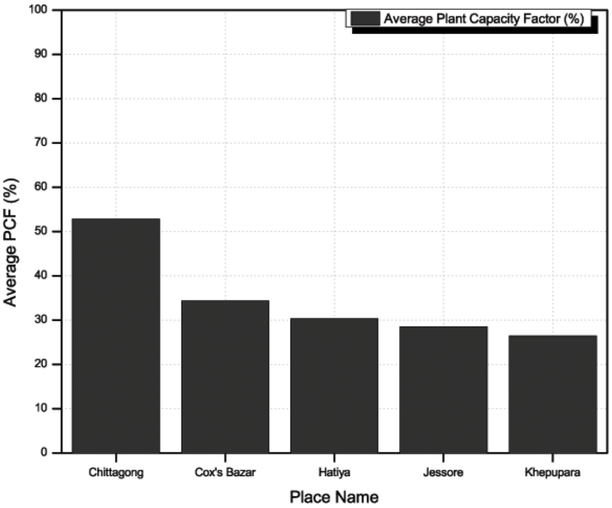

Fig. 25. Average PCF at 120m

Chittagong has the highest average PCF over the period with 53%, Cox's Bazar is very far behind at second with 34%. Hatiya, Cox's Bazar and Khepupara has 30%, 28% and 26% PCF respectively (Figure 25).

All 35 places belong to power class 1 at 50m height. Only five places e.g. - Chittagong, Jessore, Khepupara, Cox's Bazar and Hatiya belong to power class 2 or above. For small, medium and large scale power generation at least 2 or greater power class is required [11]. But there are specially design wind turbines for power class 1 sites, which work at a very small wind speed and can generate a micro scale of power [22]. Feasibility for micro scale power generation is studied in terms of plant capacity factor (PCF) at 50m for all 35 places. As standard practice PCF of 35% or more is considered economically feasible. But At the EU level, a realized capacity factor of 21%. PCF is considered 20% for asserting the site as feasible. Under above conditions, 17 sites out of 35 are found feasible for micro scale power generation.

Results are summarized in table 4. At 120m height only Chittagong, Jessore, Khepupara, Cox's Bazar and Hatiya are studied for feasibility in terms of PCF. Rest 30 sites are not studied as their power classes still remain on 1. Chittagong and Jessore are studied for large scale generation, Khepupara for medium scale, and Cox's Bazar and Hatiya for small scale generation. PCF for all five sites found more than 26%, e.g.- Chittagong 53%, Jessore 28%, Khepupara 26%, Cox's Bazar 345 and hatiya 28%. As per realized capacity factor in EU level all these sites are commercially viable at 120m height. Below table summarizes all the results. Figure 26 shows the GIS mapping of different places according to their feasibility. Different colors have been used to show there feasibility.

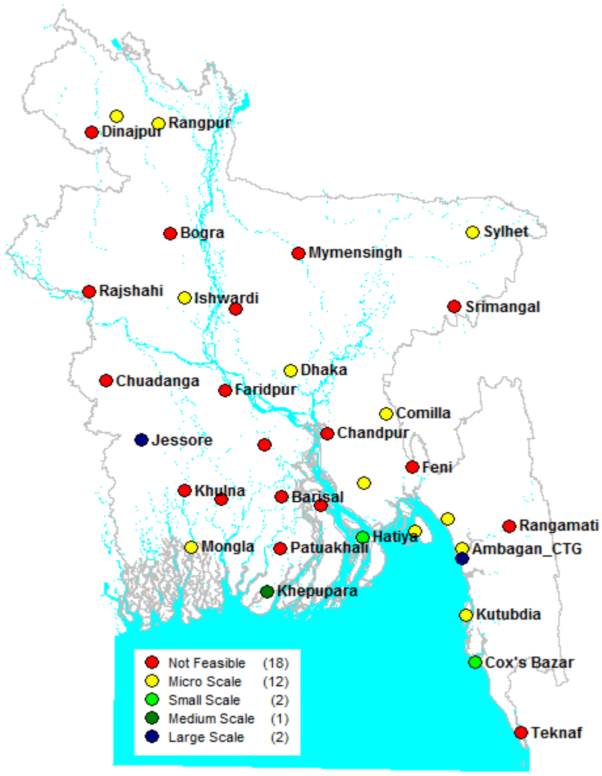

Fig. 26: Thematic GIS locations of different places in terms of their feasibility

4. Conclusion

Based on the three hourly wind speed data at 35 different location of Bangladesh the feasibility study is done in terms of Wind Power Density (WPD) and Plant Capacity Factor (PCF). The study has been carried out on wind speed data of year 2002 to 2011. The outcome of the study would help in the following ways:

1) The study will provide a reference for Bangladesh Power Development Board (BPDB) for selecting right sites for deploying wind power generation.

2) It would also provide BPDB the right information about the scale of generation they should select for economical wind power generation [19].

3) It would also provide BPDB the information of which regions of Bangladesh should be more extensively studied for chalking out more possible candidates for wind power deployment.

4) It would provide a platform for further technical and economical feasibility study of hybridizing wind power with Biogas, Solar Power, Fuel Cells, and Tidal Energy etc for standalone or grid connected power system [23-26].

5) It could also help Bangladesh Rural Electrification Board (REB) for choosing locations for solar-wind-biogas hybrid power system for domestic use or irrigation system [26].

6) There are remote locations in Bangladesh where extending grid power is not economically and technically viable, also geographically not possible. For those places wind power could be a more than adequate solution.

Table 4. Summary of results

	Wind Power Density (W/m^2)		**Power Class**		**Plant Capacity Factor (PCF) (%)**		**Feasibility**		
Place Name	**At 50m**	**At 120m**	**At 50m**	**At 120m**	**At 50m**	**At 120m**	**At 50m**	**At 120m**	**Overall**
Ambagan_CTG	32	90	1	1	21%	N/A	Micro Scale	N/A	Micro Scale
Barisal	49	141	1	1	17%	N/A	Not Feasible	N/A	Not Feasible
Bhola	7	18	1	1	9%	N/A	Not Feasible	N/A	Not Feasible
Bogra	24	68	1	1	18%	N/A	Not Feasible	N/A	Not Feasible
Chandpur	10	30	1	1	10%	N/A	Not Feasible	N/A	Not Feasible
Chittagong	187	532	1	5	61%	53%	Micro Scale	Large Scale	Large Scale
Chuadanga	13	37	1	1	12%	N/A	Not Feasible	N/A	Not Feasible
Comilla	47	132	1	1	24%	N/A	Micro Scale	N/A	Micro Scale
Cox's Bazar	72	204	1	2	29%	34%	Micro Scale	Small Scale	Small Scale
Dhaka	31	89	1	1	22%	N/A	Micro Scale	N/A	Micro Scale
Dinajpur	5	15	1	1	9%	N/A	Not Feasible	N/A	Not Feasible
Faridpur	24	70	1	1	18%	N/A	Not Feasible	N/A	Not Feasible
Feni	15	42	1	1	15%	N/A	Not Feasible	N/A	Not Feasible
Hatiya	94	268	1	2	28%	30%	Micro Scale	Small Scale	Small Scale
Ishwardi	24	68	1	1	21%	N/A	Micro Scale	N/A	Micro Scale
Jessore	180	511	1	5	32%	28%	Micro Scale	Large Scale	Large Scale
Khepupara	130	368	1	3	26%	26%	Micro Scale	Medium Scale	Medium Scale
Khulna	26	72	1	1	13%	N/A	Not Feasible	N/A	Not Feasible
Kutubdia	37	106	1	1	26%	N/A	Micro Scale	N/A	Micro Scale
Madaripur	12	35	1	1	6%	N/A	Not Feasible	N/A	Not Feasible
Maijdee Court	35	98	1	1	20%	N/A	Micro Scale	N/A	Micro Scale
Mongla	37	106	1	1	21%	N/A	Micro Scale	N/A	Micro Scale
Mymensingh	21	59	1	1	18%	N/A	Not Feasible	N/A	Not Feasible
Patuakhali	18	50	1	1	14%	N/A	Not Feasible	N/A	Not Feasible
Rajshahi	18	52	1	1	17%	N/A	Not Feasible	N/A	Not Feasible
Rangamati	25	72	1	1	10%	N/A	Not Feasible	N/A	Not Feasible
Rangpur	26	73	1	1	21%	N/A	Micro Scale	N/A	Micro Scale
Sandwip	41	116	1	1	20%	N/A	Micro Scale	N/A	Micro Scale
Satkhira	10	30	1	1	9%	N/A	Not Feasible	N/A	Not Feasible
Sitakunda	41	117	1	1	20%	N/A	Micro Scale	N/A	Micro Scale
Srimangal	36	102	1	1	16%	N/A	Not Feasible	N/A	Not Feasible
Syedpur	64	180	1	1	38%	N/A	Micro Scale	N/A	Micro Scale
Sylhet	51	145	1	1	31%	N/A	Micro Scale	N/A	Micro Scale
Tangail	9	27	1	1	13%	N/A	Not Feasible	N/A	Not Feasible
Teknaf	24	69	1	1	15%	N/A	Not Feasible	N/A	Not Feasible

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