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RESEARCH ARTICLE - ELECTRICAL ENGINEERING

Assessment of Wind and Solar Energy Resources in Bangladesh

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Abstract Wind and solar energy are the alternative energy sources that can be used to supplement the conventional energy sources particularly in Bangladesh. In this work, the aim was to assess the current wind and solar energy potential in Bangladesh. The wind data for the five stations obtained from Local Government Engineering Department have been assessed, but only two of them seem to be eligible for energy production. Annual average, monthly average and hourly average wind speeds, and wind power densities were calculated from the wind data. The Weibull distribution parameters (c and k), the dominant wind directions and the frequency distributions were also determined. Experimentally measured solar radiation data are not available over Bangladesh. Measured climatological data such as cloud cover and sunshine duration data of Bangladesh Meteorological Department from 1992 to 2001 were used for the estimation of global solar radiation as they are correlated. Techno-economic feasibility analysis is done for 100 kW grid connected wind and solar photovoltaic systems. Renewable energy-based system will bring more environmental benefits than conventional power in terms of human health, reduction of air pollution, and decrease of noise, etc. However, in the above estimation, these were not considered.

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Keywords Renewable energy · Wind power density · Solar radiation · Weibull distribution parameters · Grid-connected wind and solar systems

الخلاصة

إن الرياح والطاقة الشمسية هما مصدرا طاقة بديلة يمكن استخدامها لتكملة مصادر الطاقة التقليدية وبخاصة في بنغلاديش. ينصرف هدفنا في هذا العمل إلى تقييم طاقة الرياح والطاقة الشمسية الحاليتين الكامنتين في بنغلاديش. وقد تم تقييم بيانات الرياح في خمس محطات تم الحصول عليها من القسم الهندسي في الحكومة المحلية ولكن اثنين منهم فقط تبدوان مؤهلتين لإنتاج الطاقة. وتم حساب المتوسط السنوي، والمتوسط الشهري ، والمتوسط الساعي لسرعة الرياح وكثافة طاقة الرياح من بيانات الرياح. وجرى أيضا تحديد معاملات توزيع ويبل (ج و ك)، واتجاهات الرياح السائدة وتوزيع الترددات. إن بيانات الإشعاع الشمسي المقاسة تجريبيا لاتتوفر في بنغلادش ، لذلك استُخدمت البيانات المناخية المقاسة مثل الغطاء السحابي وبيانات مدة سطوع الشمس في إدارة الأرصاد الجوية في بنغلاديش من عام 1992م إلى عام 2001م في تقدير الاشعاع الشمسي العالمي ، وذلك نظرا لإرتباط بعضهما ببعض . وقد تم الانتهاء من تحليل الجدوى الفنية والاقتصادية لشبكة 100 كيلوواط متصلة بأنظمة الرياح والطاقة الشمسية الضوئية (PV). إن نظام الطاقة المتجددة القائم سوف يجلب منافع بيئية أكثر من الطاقة التقليدية من حيث صحة الإنسان، والحد من تلوث الهواء ، والضوضاء وما سوى ذلك . وعلى الرغم من كل ذلك فإن كل التقديرات أعلاه لم تؤخذ بعين الاعتبار.

1 Introduction

The growth of the world's human population has created several problems. One of them is global warming caused by the abundance of CO_2 in the atmosphere. Many of these gases are produced from power plants burning fossil fuel all over the world. Electricity has a direct cost associated with it and the global price of electricity has increased steadily with increasing fuel price during the past decades. In some parts of the world there is still no electricity available or it is unreliable. Energy supply is a major problem for all classes in Bangladesh. The energy consumption rate is 208 kWh/capita, which is the lowest in the world [1]. Electric generating capacity in 2010 was 5823MGW, of which 96.05 % was thermal, and the remainder hydroelectric, at 18 power stations [2,3]. The electricity infrastructure is old and badly maintained, breaks down frequently and is inadequate to meet the demand. Power cuts are frequent; many areas are only supplied for a few hours a day. Some areas have no power for days at a time when a local generator fails. The green sources of energy include solar, photovoltaic (PV), solar thermal, wind biomass, hydro and geothermal. Thus, it may be strategically important to check the possibility that a part of the energy needs of Bangladesh can be economically covered from renewable energy sources and mainly wind and solar energy. Anticipated increases in electricity rates, in tandem with potential future tax relief and government incentives for self reliance using solar and wind power, however, will likely make 'home made' energy and the industrial sector an attractive practical and financial option in the near future. For proper economical analysis, accurate knowledge of the availability and variability of solar radiation intensity is essential. The measured solar radiation data are not available in Bangladesh. It was found that wind speeds in the coastal belt of Bangladesh were the only ones which showed promise. The assessment of the suitable regions for wind energy utilization and the estimation of the expected power production of wind turbines are a prerequisite for efficient wind turbines sitting under economical, social, and environmental constraints. The estimation of the wind turbine potential is generally related to a very long meteorological study of the measures of the wind speed. Most of the previous wind speed data in Bangladesh were available from the Bangladesh Meteorological Department (BMD). Meteorological stations measure winds at lower height and it has been found that BMD data give low values due to the obstacle effect by trees and buildings close to the met stations [4]. However, normal hub-heights of modern wind turbines range from 20 to 40 m. Thus using meteorological data, designing wind energy conversion system is not significant. In 1996–1997 under the WEST project Bangladesh Centre for Advanced Studies (BCAS) with the support of Local Government Engineering Department (LGED) measured wind speed and direction at 25 m height for seven locations near the seacoast, GTZ (a German Organization) also measured wind speeds for another three coastal locations at a height of 20 m and Bangladesh Council for Scientific and Industrial Research (BCSIR) measured wind speed for Dhaka, Teknaf, and Saint Martin locations from 1999–2001 [4]. For the wind energy assessment study in the coastal areas, data have been collected by different organizations and Table 1 shows the status of the collected data.

Solar photovoltaic technology is being used commonly to generate electricity for stand alone power system. Solar radiation can be measured from meteorological parameters such as cloud cover, sunshine duration, and temperature. Bangladesh Meteorological Department (BMD) collects sunshine duration data from all BMD stations sunshine recorders. Some location data may not be of good quality because of the placement of the sunshine recorder in the ground level, for the shading or for the unsatisfactory alignment of burning with the central line. Hence predicted Global radiation using these data will give large discrepancy with the actual values. Cloud cover is a direct indicator of sunshine duration and they are correlated. An increase in cloud cover shows a decrease in sunshine duration and vice versa.

In this study, the set of wind speed data measured by Sustainable Rural Energy (SRE) of Local Government Engineering Department (LGED) for Kutubdia, Sitakunda,

Table 1 Measured wind speed at different heights and places in the coastal areas [4]

Organization	Location	Anemometer height (m)	Average speed (m/s)	Measuring period
BCAS	Kuakata	25	4.5	09/96-08/97
	Charfassion	25	4.0	
	Noakhali	25	2.9	
	Chittagong	25	3.8	
	Kutubdia	25	4.4	
	Cox's Bazer	25	3.2	
	Teknaf	25	2.8	
BCSIR	Teknaf	10	3.5	01/01-04/02
	Sant Martin	30	4.7	
GTZ	Feni	20	4.0	06/96-05/97
	Anwara	20	4.4	
	Teknaf	20	4.3	

Khagrachari, Chittagong University of Engineering and Technology (CUET) and Kuakata from June 2005 to December 2006 were used for analysis of wind resource assessment. For estimation of global solar radiation from sunshine duration and cloud cover, we have collected sunshine duration and cloud cover data for 31 stations of Bangladesh Meteorological Department (BMD) for 1981–2001. Both organizations have been using Campbell–Stokes sunshine recorders and have been measuring cloud cover by eye estimation in Octa. BMD was using the original Campbell–Stokes sunshine duration measurement cards since 1991; after that they are using locally made cards with different sensitivity than the original ones. To avoid unexpected error due to card change, studies have been done for 1992–2001 period. The long-term wind flow of Islands and the southern coastal belt of the country indicate that the average wind speed remains between 3 and 4.5 m/s for the months of March–September and 1.7–2.3 m/s for the remaining period of the year [4]. This indicates there is a good potential in islands and coastal areas for the application electricity generation from wind. But during the summer and monsoon seasons (March to October), there can be very low-pressure areas, and storm wind speeds of 200–300 km/h can be expected. Wind turbines should be strong enough to withstand these high wind speeds [5]. The long-term average sunshine data indicate that the period of bright (i.e. more than 200 W/m^2 intensity) sunshine hours in the coastal region of Bangladesh vary from 3 to 11 h daily and the global radiation varies from 3.8 to 6.4 kW h/m^2/day [11]. These data indicate that there are good prospects for solar, thermal, and photovoltaic application in Bangladesh. So, densely populated tropical country like Bangladesh could be electrified by wind/PV grid system using the inexhaustible and pollution-free solar and wind source energy without using any novel technologies. Introducing wind and solar energy sources for electricity generation in mass scale would compensate for electricity shortage and reduction CO_2 emission. In this paper, techno-economic feasibility analyses are carried out for 100 kW wind and PV grid systems. To find the optimum size of inverter and for technical analysis, simulation software Renewable Energy Technologies screen (RETScreen) is used [5].

2 Wind Resource Assessment

Wind energy varies with year, season, and time of day, elevation above ground, and form of terrain. Proper position of turbine, in windy sites, away from large obstructions, improves wind turbine's performance. Usually, the two-parameter Weibull probability density function is used to represent wind speed distributions [6]. Weibull probability distribution is used to determine parameters of the wind speeds. The Weibull distribution is a mathematical expression, which provides a good approximation to many measured wind speed distributions. The Weibull distribution is therefore frequently used to characterize a site. Such a distribution is described by two parameters: the Weibull 'scale,' parameter which is closely related to the mean wind speed, and the 'shape' parameter, which is a measurement of the width of the distribution. This approach is useful since it allows both the wind speed and its distribution to be described in a concise fashion.

For the various sources of data the Weibull probability function was utilized to approximate the probability of the occurrence of wind speeds. Weibull distribution [7] is

$$P(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)k} \quad v > 0$$
$$= 0 \quad v \le 0 \tag{1}$$

This distribution is given by Eq. 1 where k is the shape parameter and c the scale parameter.

Wind power density, expressed in watt per square meter (W/m^2), takes into account the frequency distribution of the wind speed and the dependence of wind power on air density and the cube of the wind speed. Therefore, wind power density is generally considered as a better indicator of the wind resource than wind speed. The mean wind power density available over a period T is given by Eq. 2. In this equation ρ is the air density and $\bar{E}$ is given in (W/m^2).

$$\overline{E} = \frac{1}{2}\frac{1}{T}\int_0^T \rho v^3(t)\mathrm{d}t \tag{2}$$

ρ may be taken as a constant with an error of a few percent [8]. It should be noted that the velocity expression of Eq. 2 is based on values of average speed, not instantaneous values. Also sitting within dense vegetation such as a forest or an orchard requires establishment of a new effective ground level at approximately the height where the branches of adjacent trees touch, the level below which there is a little wind. In a dense cornfield wind, this height would be the average corn height or average height of the tree canopy for a forest area. In areas of high wind, wind power can be quite reliable and inexpensive. However, for wind energy to be economically viable, it has to deliver to a wind turbine an average annual wind speed of at least 5.36 m/s[1] and above [8].

In general, daily and seasonal changes as well as wind direction are important considerations while installing a wind power systems. From five LGED stations it was found that the average annual wind speed values at 10, 20, 30 m height for the five wind stations vary from 1.73 to 4.17 m/s. The highest average annual wind speed (4.17 m/s) was observed in Kuakata and the lowest value (1.32 m/s) at Khagrachari. The analysis showed that highest wind speed was found during summer at Kutubdia and Kuakata. The annual cycle of monthly average wind speed shows fairly large seasonal variation, the appearance of which is typical for measurement sites,

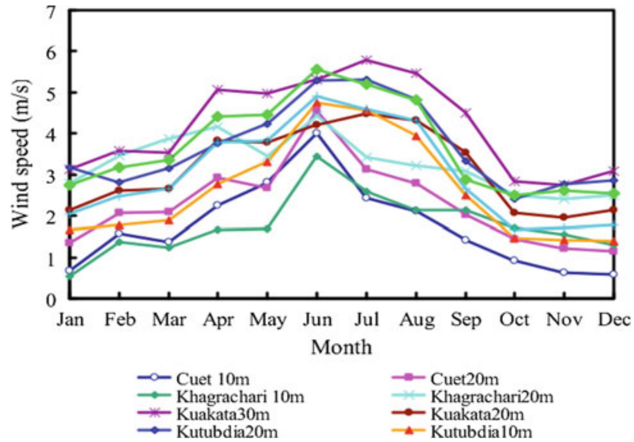


Fig. 1 Monthly variation of wind speed for sites at different heights

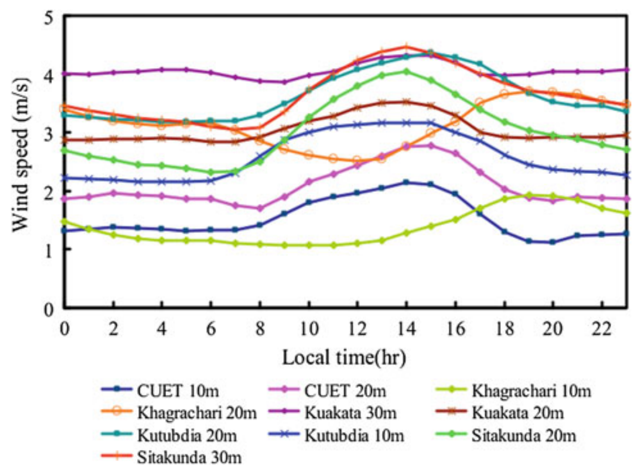


Fig. 2 Diurnal variation of wind speed for sites at different heights

with minimum values in winter (October–March) and maximum values during summer (April–September, Fig. 1). Similar variations were also observed for BCAS Kutubdia and Kuakata stations [9,10]. The analysis of the daily cycle of the wind speed at different time instants, however, suggests that the dominance of daytime winds over night winds that is characteristic of mainland measurement sites also contributes to this feature. The hourly variation of wind speed is shown in Fig. 2. There is almost no dependence of the wind speed on the measurement time for Kuakata and weak maxima become evident at afternoon for all other stations. Such a variation is similar to that observed for at BCAS wind monitoring station of Kutubdia and Kuakata wind measurement sites [9,10]. A part of this cycle is obviously due to the local sea breeze. The typical spatial scale for changes of the diurnal cycle apparently depends on many factors such as the area covered by sea breeze, the geometry of the coastal region, or the mutual orientation of the land and sea, and the direction of air flow. From the above analysis it might be concluded that the daily cycle of wind speed should be taken into account when a wind farm is planned in the vicinity of a specific site.

A wind rose is the term given to the way in which the joint wind speed and direction distribution is defined. The wind speed data for LGED stations were grouped into 12 directional sectors: north–north west (NNW), north (N), north–north east (NNE), east–north east (ENE), east (E), east–south east (ESE), south–south east (SSE), south (S), south–south west (SSW), west–south west (WSW), west (W), and west–north west (WNW). So, each one extended over 30° according to the direction from which the wind blows. The design of a wind farm is sensitive to the shape of the wind rose for the site. In some areas, particularly in areas where the wind is driven by thermal effects, the wind can be very unidirectional. Wind roses providing the percentage of wind direction for different stations for the whole year have been constructed as shown in Fig. 3. The coastal and mainland wind are less directionally homogeneous and only show a slight prevalence of north and south-west winds. The coastal winds are mostly driven by large-scale atmospheric dynamics and are less affected by local orography and obstacles whereas the inland sites (CUET and Khagrachari) are strongly effected by orography and obstacles.

The Weibull parameters were calculated by least square method. Table 2 shows the corresponding values of k and c for each location for each month. From Table 2, it is found that the value of k during summer for all stations is higher and that of winter is lower. A small value of k indicates widely dispersed data, i.e., the data tend to distribute uniformly over a relatively wide range of wind speed. If mean wind speed is low, this has a negative implication on wind power generation because the station does not experience enough wind speed to operate a wind turbine. For large values of k, the majority of wind speed data tend to fall around the mean wind speed, and if the mean wind speed is high, then the station experiences enough wind speed to operate a wind turbine at least for a short period of time. The frequency distribution functions for different stations and heights are shown in Figs. 4, 5, 6, 7 and 8 enable one to estimate the probability of exceeding certain wind speed thresholds that could be important for wind farm planning.

Wind power density is considered to be the best indicator to determine the potential wind resource, which is critical to all aspects of wind energy exploitation, from the identification of suitable sites and predictions of the economic viability of wind farm projects through to the design of wind turbines themselves. Monthly and diurnal variation of wind power density is shown in Figs. 9 and 10. The power density was calculated using Eq. 2. As wind power density depends on the cube of speed v^3 the available wind energy is much higher during the windy months. During June and July wind power density is higher than other months. Maximum wind power density was in Kuakata (88 kW/m^2) at height 30 m and minimum in Khagrachari (13 kW/m^2) at a height 10 m.

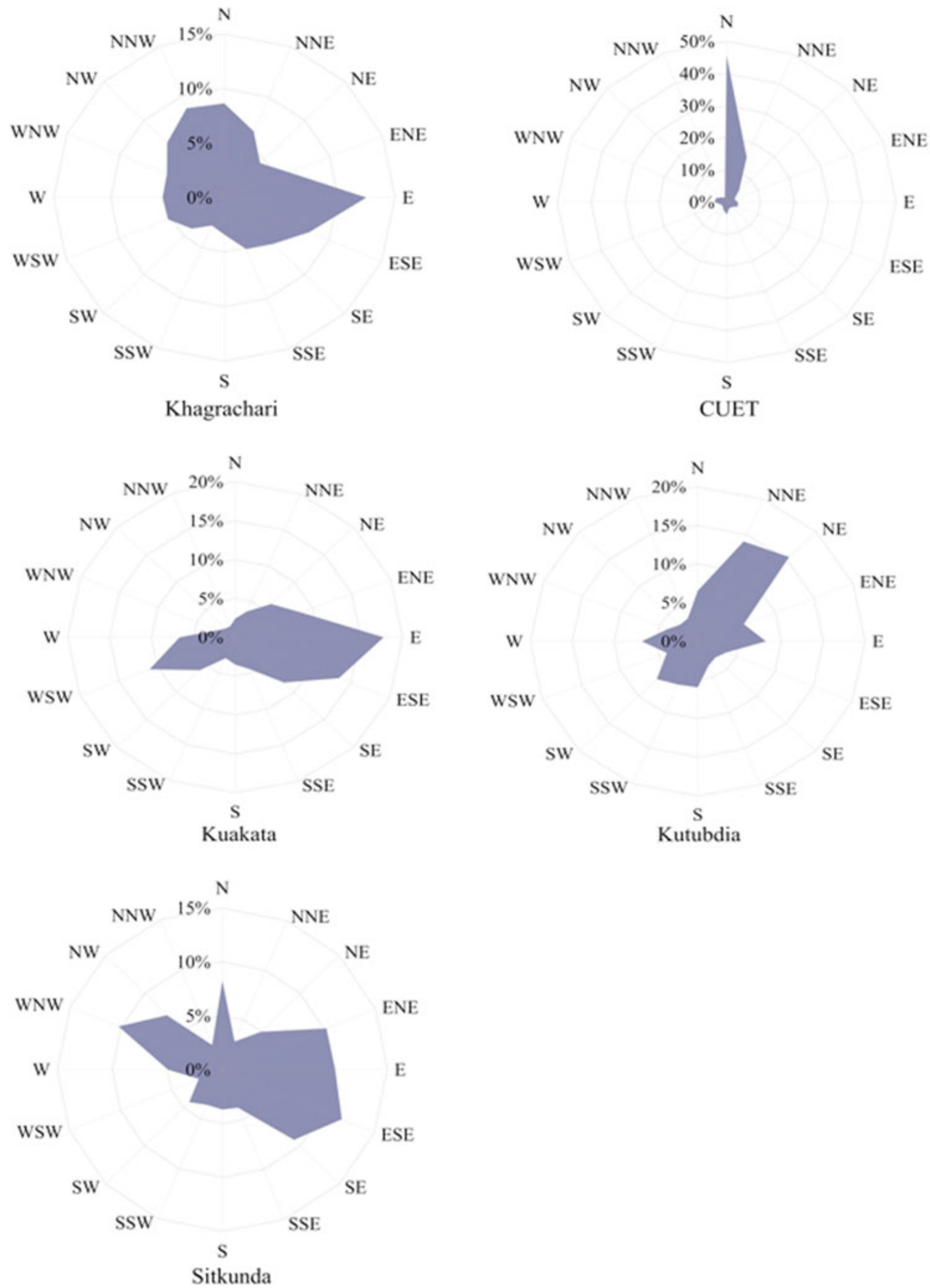


Fig. 3 Wind rose for different locations showing percentage of wind direction

3 Solar Radiation Assessment

A study [10] showed that the cloud cover measurements are satisfactory in all the BMD stations. Variation of sunshine duration and cloud cover with years are shown in the Figs. 10 and 12. According to the method suggested by Barbaro et al. [11] the relation between the relative sunshine duration and state of the sky is

$$\frac{n}{N'} = \frac{an_1 + bn_2 + cn_3}{n_{123}}, \quad (3)$$

where n_1 is the number of clear days, n_2 is the number of mixed days, n_3 is the number of overcast days in a month, $n_{123} = n_1 + n_2 + n_3$ is the total number of days in the month under consideration, and a, b, c are climatological parameters. N' is the period when the Campbell–Stokes sunshine

Table 2 MBE, RMSE and MPE for global and diffuse radiation correlations

MBE	RMSE	MPE
9.246	32.92	14.72

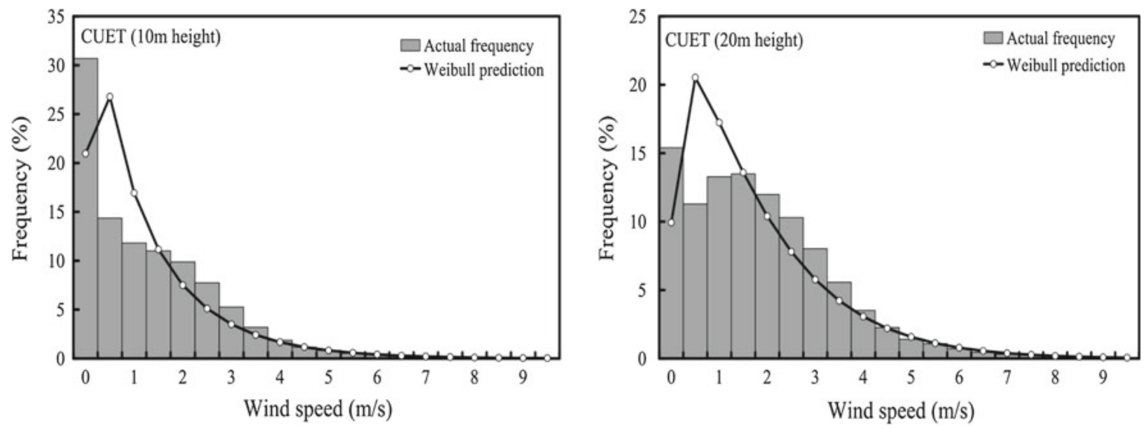


Fig. 4 Actual and predicted wind speed probability for CUET, for different heights

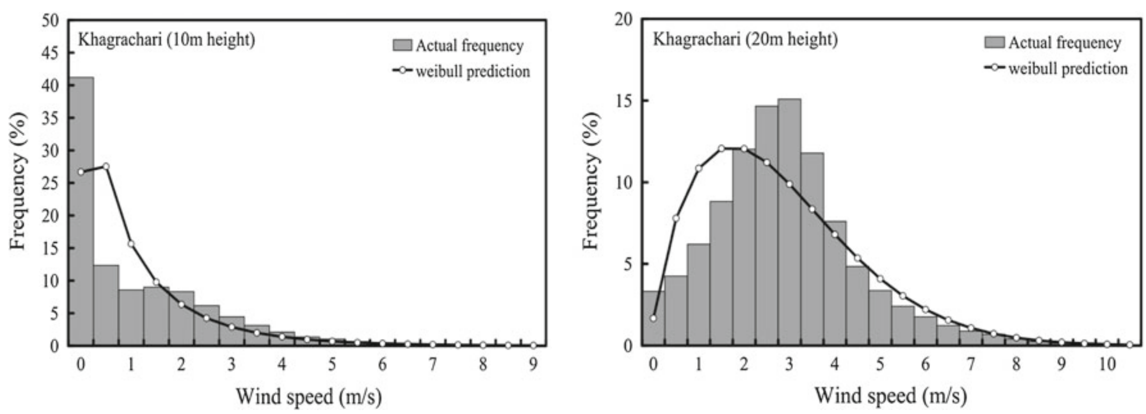


Fig. 5 Actual and predicted wind speed probability for Khagrachari for different heights

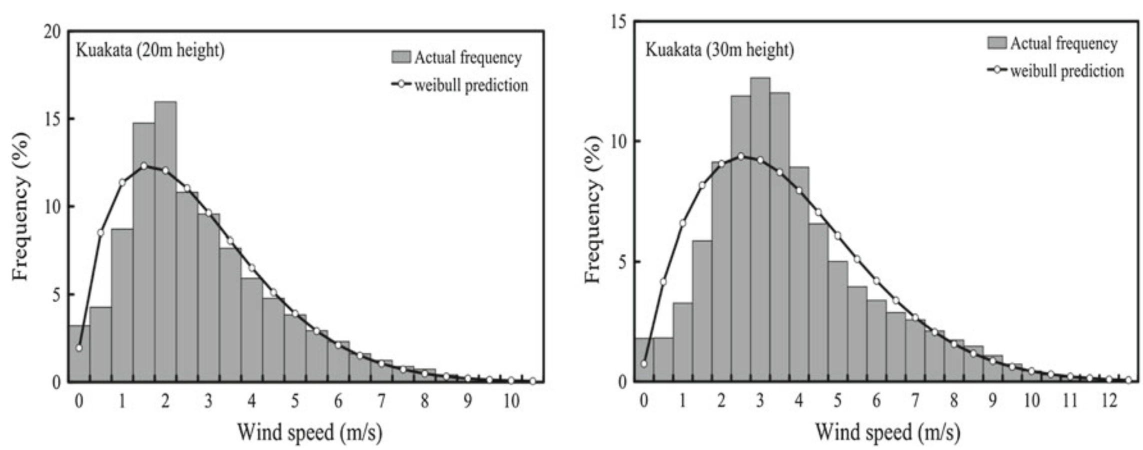


Fig. 6 Actual and predicted wind speed probability for Kuakata for different heights

recorder remains sensitive over the representative day for the month and

$$N' = \frac{\arccos\left(\frac{\cos 85 - \sin\phi\sin\delta}{\cos\phi\cos\delta}\right)}{7.5} \quad (4)$$

ϕ is the latitude of the station and δ is the declination [13]. Generally, to estimate the monthly averaged daily global radiation on a horizontal surface, a simple and well-known model used is the Angstrom equation modified by Page [14]

$$\frac{\bar{H}}{\bar{H}_0} = a + b\frac{\bar{n}}{\bar{N}} \quad (5)$$

$\bar{H}/\bar{H}_0$ is the ratio of monthly averaged daily global to monthly averaged daily extraterrestrial radiation on a hor-

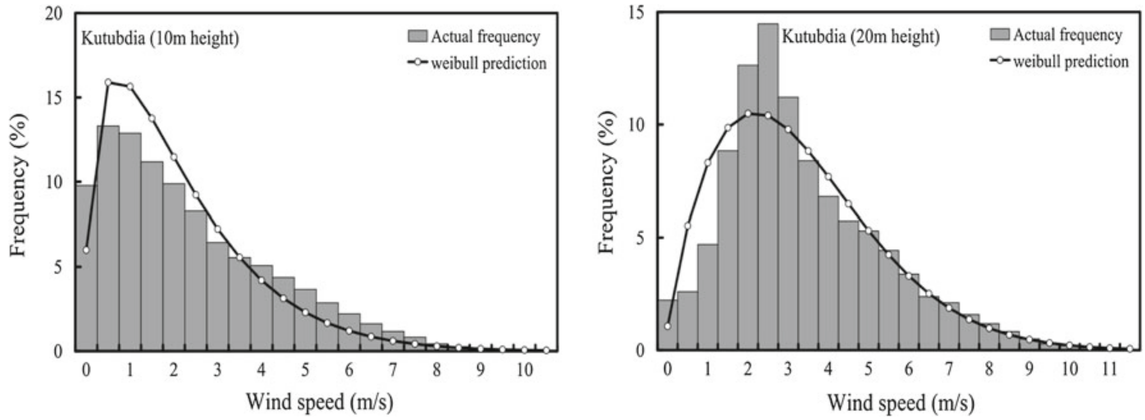


Fig. 7 Actual and predicted wind speed probability for Kutubdia for different heights

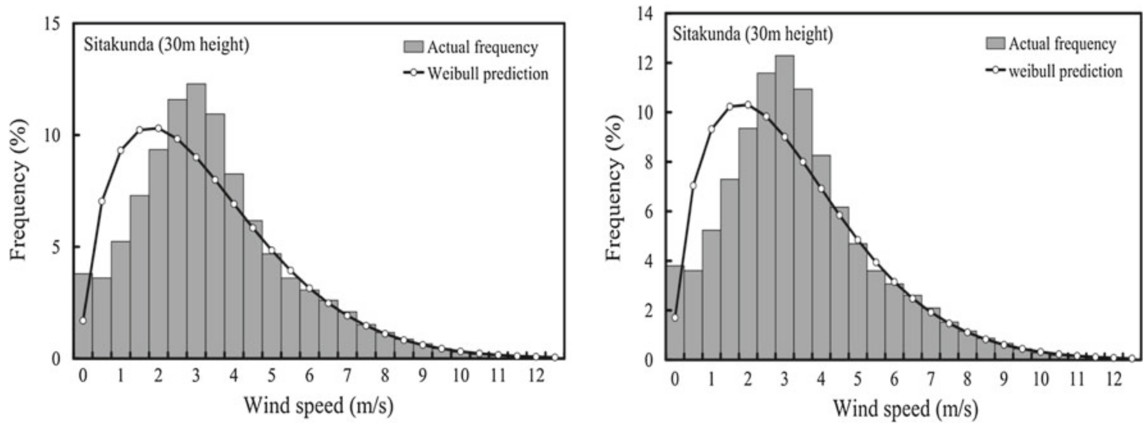


Fig. 8 Actual and predicted wind speed probability for Sitakunda for different heights

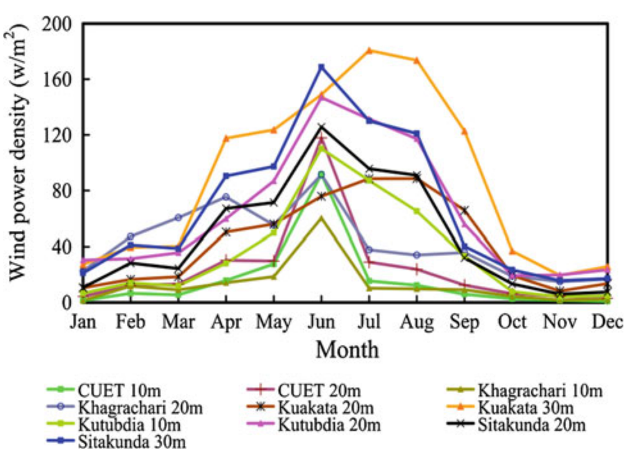


Fig. 9 Monthly variation of wind power density for different station and heights

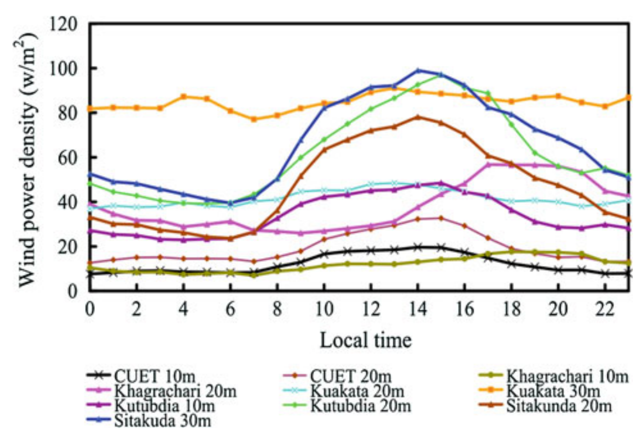


Fig. 10 Hourly variation of wind power density for different station and heights

izontal surface [15]. This ratio, known as clearness index $\bar{K}_T$, gives the percentage deflection by the sky of the incoming global radiation and therefore indicates both the level of availability of solar radiation and changes in atmospheric conditions in a given locality while relative sunshine duration, $\bar{n}/\bar{N}$ is a measure of the cloud cover. Here, a and b are regression coefficients. H_0 and N were evaluated according to equations reported in Iqbal [16] for sunshine duration and global radiation relation. The parameters of Eq. 5 have been chosen from a recent work of Ghosh et al. [17]. Monthly

Fig. 11 The variation of the yearly averaged daily sunshine duration over different stations

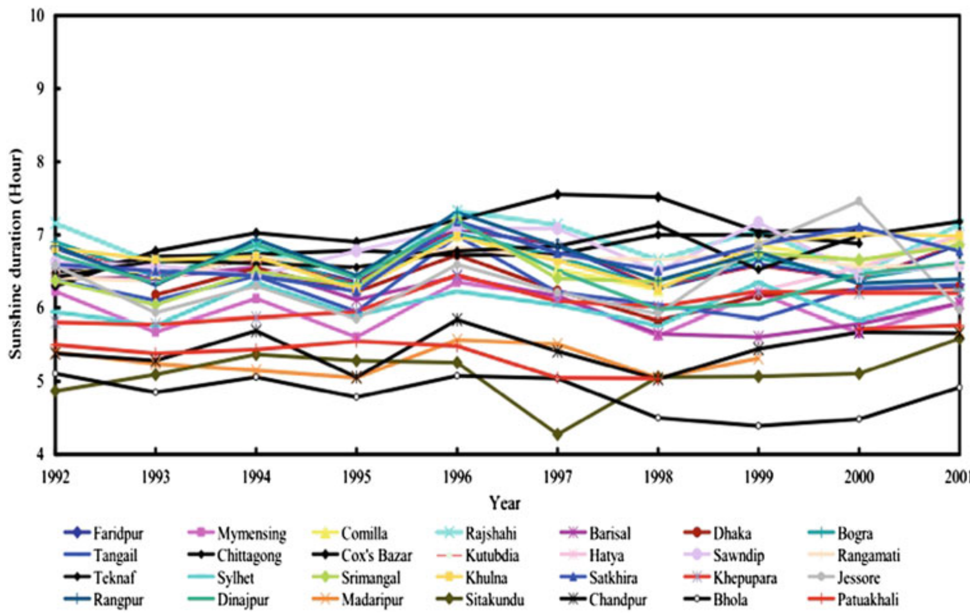
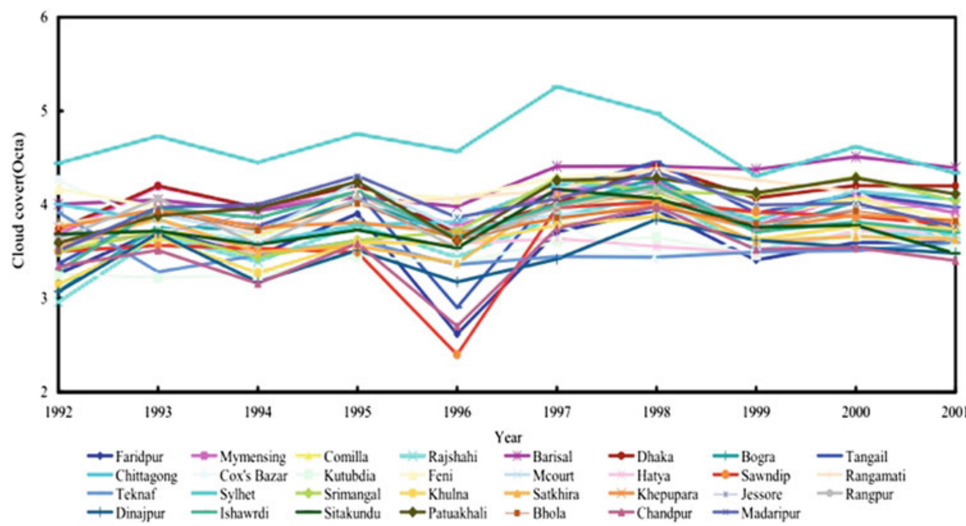


Fig. 12 The variation of the yearly averaged daily cloud cover data over different stations



variation of global solar over different stations are shown in (Fig. 13).

In this study three methods are used to evaluate the accuracy of the correlations described above. The root mean square error is defined as

$$\text{RMSE} = \left\{\left[\sum (\bar{H}_{\text{dical}} - \bar{H}_{\text{dim}\,eas})^2\right] \Big/ n\right\}^{1/2} \tag{6}$$

where $\bar{H}_{\text{dical}}$ is the ith calculated value, $\bar{H}_{\text{dim}\,eas}$ is the measured value, and n is the total number of observations. The mean bias error is defined as

$$\text{MBE} = \left[\sum (\bar{H}_{\text{dical}} - \bar{H}_{\text{dim}\,eas})\right] \Big/ n \tag{7}$$

The mean relative percentage error is defined as

$$\text{MPE} = \left[\sum \left(\frac{\bar{H}_{\text{dim}\,eas} - \bar{H}_{\text{dical}}}{\bar{H}_{\text{dim}\,eas}}\right) \times 100\right] \Big/ n \tag{8}$$

In the third method the sign of the errors is neglected in the summation and all the percentage errors are added up while calculating the mean. The errors for the hourly global radiation prediction methods are calculated using Eqs. (6–8) and given in Table 3. The RMSE and MBE are in W/m^2.

4 Techno-Economical Study of Grid-Connected Wind and PV Systems

As some of the coastal inland parts may be viable for wind energy generation and some of the northern parts are best for solar energy, renewable based grid connected system for both of the locations have been analyzed. It has been found in the WAsP analysis and resource map developed by

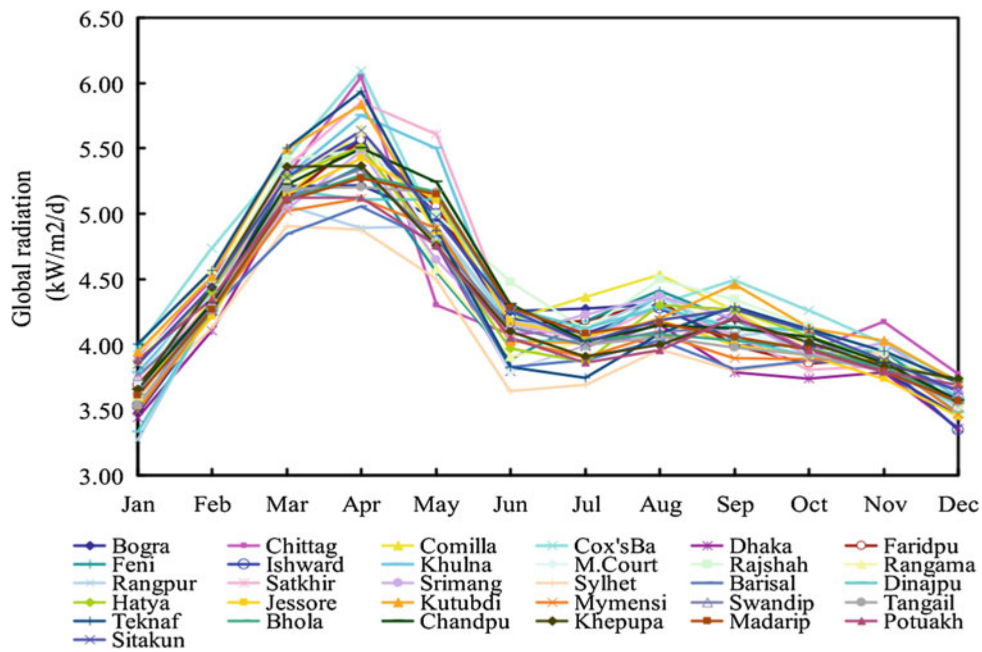


Fig. 13 Global solar radiation over different stations of Bangladesh

Table 3 Output of RET Screen for a 100-kW grid connected wind energy system where wind power density is around 200 W/m^2

Parameter	Unit	Value
Annual wind power density	W/m^2	200
Height of wind power density	m	50
Wind plant capacity	kW	100
Gross energy production	MWh	169
Wind plant capacity factor	%	17
Renewable energy delivered (Annually)	tCO_2/year	153
Net GHG reduction (Base case—Diesel)	tCO_2/year	171
Initial cost	BDT	18,637,500
Energy production cost	BDT/kWh	5.14

Table 4 100 kW Grid-connected solar energy system

Parameter	Unit	Value
PV energy absorption rate	%	100
Overall PV system efficiency	%	12.3
PV system capacity factor	%	6.8
Renewable energy collected	MWh	156.29
Renewable energy delivered	MWh	148.47
PV array area	m^2	704.9
Initial cost	BDT	33,793,648
Energy production Cost	BDT/kWh	09.68
Net GHG Reduction (Base case—Diesel)	tCO_2/year	164.84

RISOE that some of the coastal inland parts may be suitable for small wind energy generation where wind power density is around 200 W/m^2 [4]. Therefore, an analysis has been done for a grid connected wind energy system. Table 4 shows Output of RET Screen for a 100-kW Grid connected wind energy system where wind power density is around 200 W/m^2. Energy production cost in Table 4 indicates that there should not have any doubt to connect the wind energy system to the national grid in Bangladesh. Figure 14 depicts that cost of energy (COE) of a grid connected wind system increases with decrease in wind power density. The location with a wind power density 150 W/m^2 and above is economically feasible and such a system can be implemented.

The modules are faced with an angle of same as the latitude angle of the site. For this study, solar panel model mono-Si-BP4175, capacity per unit 175 W and efficiency 12.39 %. RETScreen simulates the optimum sizes of the technologies that meet the maximum grid demand of 100 kW for the selected site under the given condition of solar resources. Maximum energy generated in April is 21.4 MWh, and minimum energy generated in September is 11.32 MWh, and annual total production is 148.475 MWh. Per unit energy production cost found for the proposed project is 9.68 BDT, which is competitive with diesel-based grid power generation. By using average monthly highest and lowest solar radiation at different parts of the country with same parameters, the production cost per unit of electricity is found to be 4.24 BDT to 21.05 BDT. Sensitivity analysis results due to change of PV cost and discount rate are shown in Figs. 15 and 16, respectively. It is found that per unit electricity production cost is 4.24 BDT and 14.00 BDT when the PV panel costs are 100 BDT/Wp and 350 BDT/Wp, respectively. Higher discount rate increases the electricity production cost. It is found that the electricity production cost is 9.00 BDT when

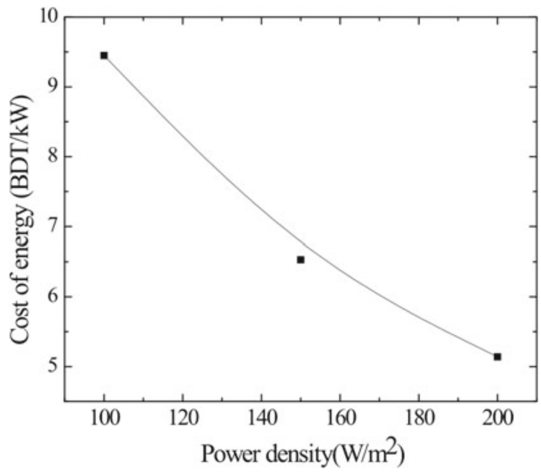


Fig. 14 Production cost of energy at different power density in the coastal part of Bangladesh

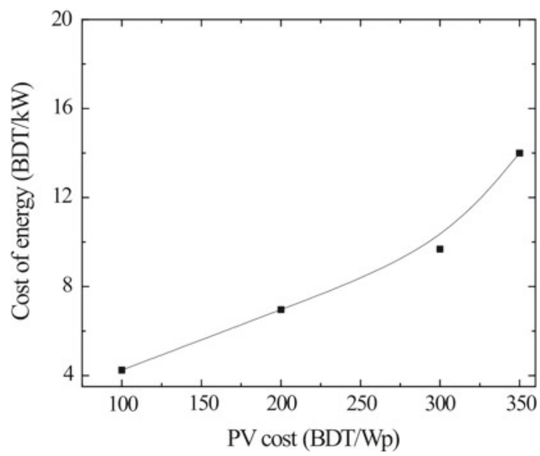


Fig. 15 Sensitivity analysis due to the change of PV cost for the grid-connected system

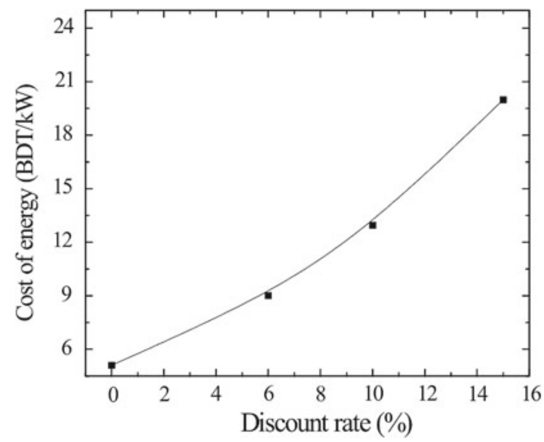


Fig. 16 Sensitivity analysis due to the change of discount rate for the grid-connected system

the discount rate is 6 %, and the cost reaches to around 20.05 BDT when the discount rate is 16 %. PV grid electricity generation system could be effective for extending the grid connection and available power for all. This study examines the feasibility of PV grid system for 100 kW generation plant. It is found that the per unit electricity production cost from the studied system is cost-competitive with grid-connected diesel power generation which is around 15–18 BDT [18].

5 Conclusions

The study reveals that Kutubdia and Kuakata have potential for wind power generation and consistent with other studies, such as BCAS measurement sites. We have used short-term data for the analysis. There is a general claim that minimum of 10-year data are required for proper assessment of wind resource at a particular site. It is required to measure wind speed for different heights and terrain effect to find out exact potential of each sites. Finally we realize that, the present work is only a preliminary study in order to assess wind energy of the selected sites and will give useful insights to engineers and experts dealing with wind energy. In Bangladesh generally a number of foggy days can be seen in January. For this reason we have correlated meteorological parameters for 11 months (except January). For estimation of sunshine duration we have calculated the ratios of measured and estimated values for satisfactory stations and considered that as fog factor (value 0.85–1.00) for this month. The monthly averaged daily global radiation varies from 3.2 W/m^2/day to 6.1 kW/m^2/day. The variations of global solar radiation in Bangladesh can be divided into two groups—the low irradiation values being associated with high cloud while the high values are associated with low cloud cover. The high values of global solar radiation were observed during summer while low radiation was observed during winter. Grouping the Meteorological stations according to their position above or below 23.5° previously a work [19] had been done to predict sunshine duration from cloud cover. That method had standard deviation of *n* 0.45 h. To get sunshine duration from rainfall data, the previous work [19] had been done grouping rainfall stations according to different rainfall range. That technique had an average standard error 0.44 h. This present work has an average standard deviation of 0.46 h, which is almost similar to that of the previous work [11]. From the economic analysis results, it can be observed that the grid-connected wind/PV system installed in Bangladesh provides the best case even excluding the addition of environmental externalities. In terms of environmental impacts, PV does not produce any pollution. The analysis shows that power systems using renewable energy sources can be economically attractive, particularly when environmental benefits are used in the calculation. Environmental benefits may include human health improvement, air pollution decrease, noise reduction, etc.

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