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Feasibility study of a renewable power plant at Kuakata in Bangladesh

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ABSTRACT

This study is performed to show the economic viability of an off-grid isolated renewable energy based power plant to meet the energy demand of a remote area at Kuakata in Bangladesh. A hybrid renewable system is proposed by comparing the feasibility of various combinations of system components for different sensitivity cases using the hourly load data and the monthly average wind and solar resources. The net present cost (NPC) of this system is 91,98,357 Tk (1USD=69.34Tk) and the cost of energy (COE) is 22.43 Tk/kWh to meet a load demand of 60kWh/d for domestic use by considering a maximum annual capacity shortage of 5%. This study also reveals that the break even distance of grid extension is about 15 km. This hybrid system would help to mitigate 20 t of CO_2/yr GHG (green house gas) from the atmosphere by replacing the existing the diesel generator of same power.

KEYWORDS

Wind energy;
Solar energy;
Hybrid system.

INTRODUCTION

Due to materialistic life styles and industrialization, the energy demands are increasing rapidly but the production is not escalating at that rate due to the unavailability and gradual appreciation of the conventional fossil fuel. The energy consumption per capita electricity is 144 kWh which is the lowest in South Asia[1] and less than 20% of the total population have access to electricity. The rate of electricity penetration in rural areas could be less than 1% per year[2]. Thus, the economic growth in these areas is obstructed due to lack of electricity[3]. Dobozi and Pohl showed that aggregate economic activity and electrical power consumption was closely related[4]. The study also showed electrical consumption and Gross Domestic Product (GDP) elasticity were close to a one to one ratio. The initialized domestic production depends on the electricity and the growth rate of electricity affects the GDP. Energy is one of the most important ingredients required to alleviate poverty, realize socio-economic and human development. Presently, energy crisis is one of the major challenges, which is affecting socio-economic development. The electricity shortage in Bangladesh was 1000 MW with a demand of 4806 MW on 2006 and at the year 2009, it has faced an electricity shortage of about 1400-1800 MW against a load demand of 5000 MW[5]. A conventional power plant is generally run by the fossil fuels which affect the environment and the system becomes inexpensive due to increasing trend of the price of fossil fuels. In this reality, fully renewable energy based power plant with more efficient conversion technologies can have positive socio-economic effects an if externalities such as health effects are included, even more benefits can be expected[6]. Recently, the government of Bangladesh has approved the renewable energy policy[7] of Bangladesh. The major objective of the policy on renewable energy of the government is to produce power utilizing renewable energy to contribute to at least 5% by 2010 and 10% by 2020 of the total demand. This target will ensure optimum development of all renewable energy sources[8] (Bangladesh economic review, 2009).

The coastal area of the country has an average wind speed 4 - 6m/s which indicates that wind based power plant can be implemented in the potential sites[9]. For the first time, Bangladesh Power Development Board (BPDB) has established a pilot project of 0.90 MW capacity of the grid-connected wind energy at Muhuri Dam areas in Feni district and target to reach up to 10MW at the same place. Beside this, LGED installed 10kWp in wind-PV hybrid system at St. Martins island. BPDB has established a 1 MW off-grid wind-battery power plant which is supplying 0.60 to 0.80MWh electrical energy every day at 11kV at Kutubdia island[5, 10].

The annual average solar radiation on horizontal surface varies from 4 to 6.5kWh/m^2 per day[11]. Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. A solar-powered irrigation system has been developed by converting diesel-run irrigation pump on solar power which can save 760 MW power and 800 million liter diesel every year if the conventional power and diesel-run irrigation pumps are converted to solar power systems[12]. Currently, 200,000 households are electrified by solar energy systems and the gross amount of solar power systems is about 12 MW. Bangladesh government has taken initiative to install one million solar home systems by 2015 (~50 MW) which will prevent 84,000 tons of CO_2 per year[13].

Solar and wind energy systems are omnipresent, freely available, environmental friendly and they are considered as promising power generating sources due to their availability and topological advantages for local power generations. Combination of two energy sources is capable to ensure a reliable and continuous output is called the hybrid system. If a stand-alone PV system is used, it requires to either increasing the size of PV array or the size of the battery bank to meet the load demand. Again by using a wind-PV hybrid system the size of the storage device can be reduced which in turns reduced the COE. Several studies[14-16] showed that a hybrid energy system is more economic than stand alone system.

An optimum solar–wind hybrid system has good compensation characters between solar and wind sources. The PV–wind hybrid system is becoming popular for power generation in remote area due to advancements in renewable energy technologies and substantial rise in prices of petroleum products. The cost of power generation from a hybrid system can be minimized through proper equipment sizing and load matching[17]. Bernal-Agustin (2009)[15] showed that a stand-alone hybrid renewable energy system incurs lower costs and demonstrates higher reliability than a photovoltaic (PV) or wind system. A hybrid power system is not only feasible for domestic use of small community but also for a large hotel (Dalton et al., 2008[18]), an ICT telecentre[19] and a secondary school[20]. Though the primary installation cost of a renewable energy based power plant is very high but operating and maintenance cost are negligible compare to a conventional one[21]. Saheb-Koussa et al., (2009)[22] estimated the appropriate dimension of stand-alone hybrid PV-wind/diesel with battery storage that guarantee the energy autonomy of typical remote consumer with lowest COE for six locations in Algeria. Another study[23] discussed the method of improvement of the performance of a hybrid system to establish techniques for accurately predicting output and reliably integrating the system with other renewable or conventional power generation sources. Due to the long distance and difficult to access, in remote area, the overall system used in these applications must be reliable[24].

The scope of this work concentrates to optimize a wind based off-grid power plant at Kuakata. The proposed power plant is 100% renewable energy based, that would cater to 25 households and a primary school. The proper combinations of plant equipment were chosen on the basis of technical as well as economic performance among all possible combinations. A combination of primary and secondary data was used for extensive analysis to arrive at optimum solutions. For optimization analysis, HOMER has been used, which is computer based simulation-optimization model developed by National Renewable Energy laboratory, USA for evaluating design options for both off-grid and gird connected power systems. The optimization and sensitivity analysis algorithms of the simulator allow evaluating the economic and technical feasibility of a number of technology cost and availability of energy sources. The effect of load size in the hybrid system will be discussed and threshold load will be determined. Moreover, the comparison of this system with grid and the mitigation of harmful green house gases (GHGs) from the atmosphere by replacing the renewable energy based power system will be studied.

SOLAR RESOURCE

Experimentally measured solar radiation data were not available for the site, so sunshine duration data were collected from Bangladesh Meteorology Department (BMD) at Kuakata station which is in close proximity to the selected site. The original Angstrom-type regression equation related monthly average daily radiation to clear day radiation at any location is as follows:

$$\frac{H_g}{H_c} = \alpha + b\frac{S}{S_O} \quad (1)$$

Where $S_O = 2\left[\frac{\omega_S}{15}\right]$, H_g is the monthly average daily global radiation, *Hc* is the average clean sky daily radiation on a horizontal surface, S is the mean monthly average daily sun shine hour, S_O is the maximum possible sun shine hour, ω_S is the sunshine hour angle and a, b are the empirical constants.

The monthly average of the maximum possible daily hours of bright sun shine can be computed from the above equation. Page (1964)[25] modified the method based on extraterrestrial radiation on a horizontal surface by the relation,

$$\frac{H_g}{H_o} = \alpha + b\frac{S}{S_O} \quad (2)$$

Where H_O is the monthly average of the daily extra terrestrial radiation.

But Hussain and Haider (1981)[26] estimated the value of empirical constants a and b from the weather data of Bangladesh and modified the above equation as,

$$\frac{H_g}{H_O} = 0.18 + 0.39\frac{S}{S_O} \quad (3)$$

Where H_g/H_0 is known as clearness index K_T, which means the transmission of radiation through the atmosphere. Values of S can be calculated from the Cooper formula (1969)[27]. Grahamand and Hollands (1990)[28] showed the way to estimate the hourly K_T values from daily K_T by using an empirical model. The global solar radiation over Kuakata is shown in Figure 1.

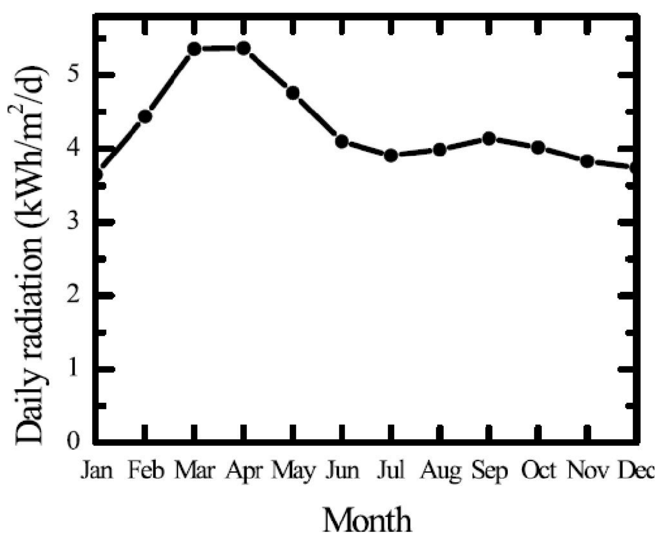

Figure 1 : Monthly variation of global horizontal radiation.

WIND RESOURCE

Wind speed is not a constant phenomenon and varies with year, season, and time of day, elevation above ground, and form of terrain. Bangladesh is situated in tropical area and for this reason the monsoon flows over the country at summer season. Since Kuakata is a coastal area of Bangladesh, the wind potential is notable here. Wind speed data measured by Local Government Engineering Department (LGED) at 20m and 30m heights from June 2005 to December 2006 were used to measure the wind potential at Kuakata. The diurnal and seasonal variations of wind speed are shown in Figures. 2(a) and 2(b).

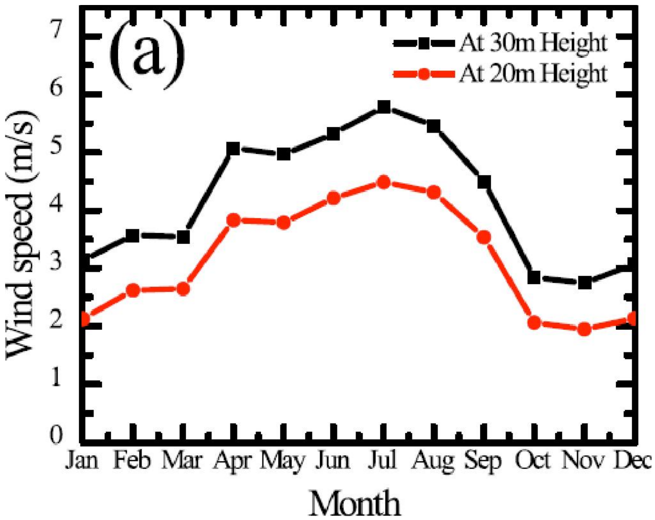

Figure 2 : (a) Monthly variation of wind speed of Kuakata at 30m and 20m elevation from the ground.

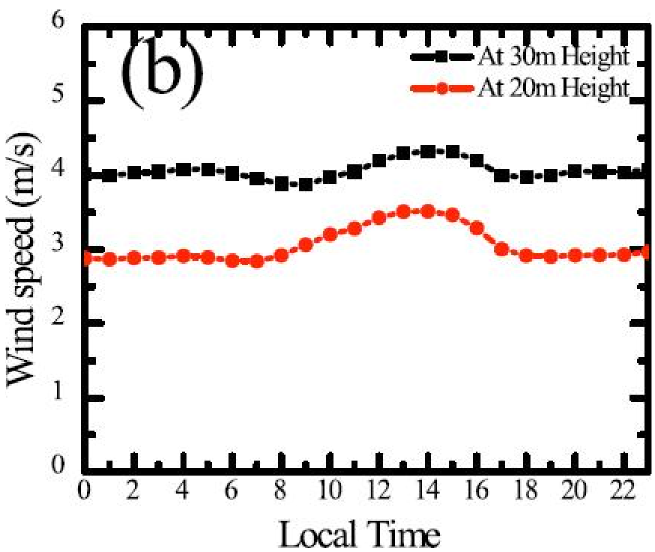

Figure 2 : (b) Hourly variation of wind speed of Kuakata at 30m and 20m elevation from the ground.

Figure 2(a) shows that the wind speeds are not constant phenomena over the season. The maximum wind speed is available during summer due to the effect of monsoon. The lowest wind speed is observed at winter season (October to February). The hourly variation of wind speed is quite steady with a little peak at afternoon and the wind speed at a height 30m from the ground is always greater than the cut in speed of the wind turbine. This means that a continuous energy can be extracted from wind at this area which is very essential for any wind farm.

The frequency for particular wind velocity can be predicted by a mathematical expression the Weibull function and it can be expressed by the following formula:

$$f(v)\left\{-\left(\frac{K}{c}\right)-\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right]\right\}\text{when } v\rangle 0 \qquad (4)$$

=**O** elsewhere

where c>0 is a scale parameter and k>0 is a shape parameter. For 0<c<1, the Weibull distribution has decreasing hazard function. With c>1, the Weibull distribution has an increasing hazard function. When c=1, the Weibull reduces to an exponential distribution. Generally, the shape parameter represents the dispersion of the data. It can be noted here that[29] c and k are dependent through the equation:

$$\log c+\frac{1}{k}\log 2=\log(\text{median}) \qquad (5)$$

And these parameters are related to the average wind speed by the equation:

$$\bar{v}=c\Gamma\left(\frac{1}{k}+1\right) \qquad (6)$$

Where Γ is the gamma function. The comparison between the probability of predicted and actual wind speed is shown in the following Figure 3.

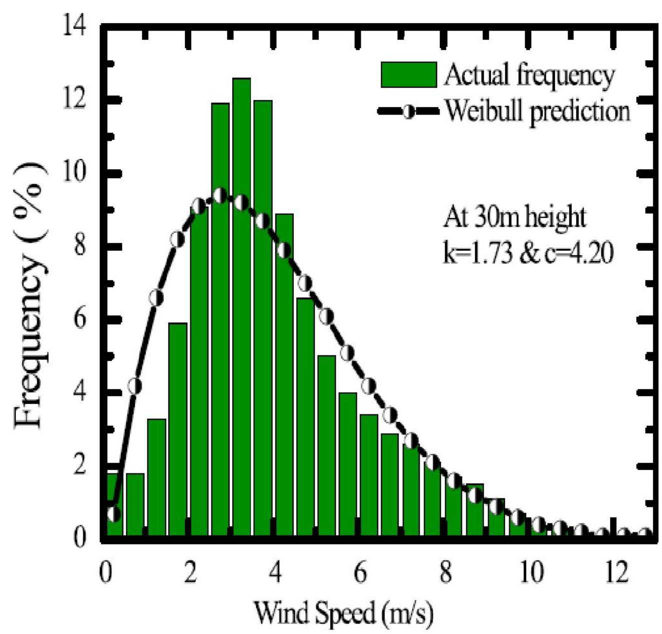

Figure 3 : Comparison between the actual frequency and Weibull prediction for wind speed at 30m height at Kuakata.

LOAD CONSUMPTION

Most of the inhabitants of Kuakata are tribal and their occupation is mainly fishing. They are deprived of using the modern electrical and electronic devices due to unavailability of enormous amount of power from national grid. Load consumption data are not available for the proposed site. Basically, they use electricity for lighting, cooling and entertaining[30]. Presently, most of the electricity at Kuakata is consumed by the incandescent lamps. We estimate 35% reduction is possible by replacing all light bulbs with compact fluorescent energy saving lamps. In this study a hypothetical community of 25 households is considered and each of them contains five members on an average. Each household uses maximum three energy saving fluorescent lamps (each of 20 watts), two ceiling fans (each of 75 watts) and a television (80 watts). Figure 4 shows the variation of typical load consumption in a rural area for domestic use with local time for three different seasons. It is also evident that the load at the spring or autumn season is intermediate between summer and winter. The higher demand exists during summer while relatively smaller load requirements are found during rest of the period. The daily energy consumption is relatively higher between 16h and 22h.

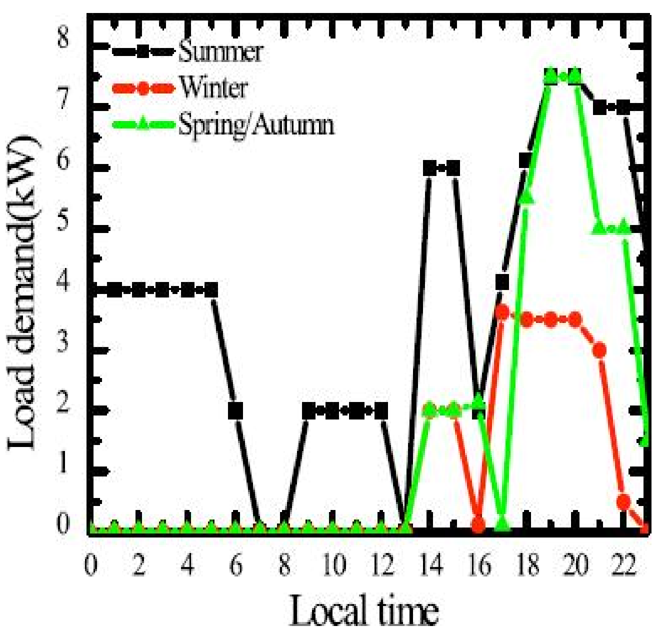

Figure 4 : Variation of load with local time and seasons.

SYSTEM COMPONENTS

Solar-PV module

In the present case polycrystalline silicon photovoltaic (PV) panels are considered for analysis. Only the rated power of PV panels is used and the area is irrelevant. This type of PV panel is considered to be placed with south facing and a slope of about 22^0 with earth surface. The output power of a solar panel mainly depends on the incident solar radiation with a directly proportional relation. Again there is a strong dependence of output power with temperature. The decrease of output power with increase of temperature can be estimated by temperature co-efficient. HOMER can analyze the probability of output power for various times with given solar radiation data. This software uses the following equation to calculate the output of the PV array:

$$\mathbf{Ppv = Ypv\, fpv\left(\frac{G_T}{G_{T,\ STC}}\right)[1+\alpha p(T_C - T_{C,\ STC})]} \qquad (7)$$

Where, Y_{pv} is the rated capacity (kW) of the PV array, meaning its power output under standard test conditions (STC). STC means a radiation of 1 kW/m^2, a cell temperature of 25°C, without wind flow. Standard test conditions do not reflect typical operating conditions, since full-sun cell temperatures tend to be much higher than 25°C. Here, f_{pv} is the PV derating factor (%), G_T is the solar radiation incident on the PV array in the current time step (kW/m^2), $G_{T,\ STC}$ is the incident radiation at standard test conditions, αp is the temperature coefficient of power (/°C), T_c is the PV cell temperature in the current time step (°C), $T_{C,\ STC}$ is the PV cell temperature under standard test conditions (25°C). The effect of temperature is neglected and the equation (7) takes the form:

$$\mathbf{Ppv = Ypv\, fpv\left(\frac{G_T}{G_{T,\ STC}}\right)} \qquad (8)$$

The estimated primary cost of PV-module is 2,50,000Tk/kW including the shipping, tariffs, installation and dealer mark-ups. The replacement cost is 2,00,000Tk/kW and the operating and maintenance cost is 500 Tk/yr-kW. The parameters considered for the simulation of PV module are exposed in TABLE 1.

TABLE 1 : Technical parameters for the PV module.

Criteria	Unit	Values
Output current	-	DC
Lifetime	Years	20
Derating factor	%	80
Slope	Degrees	22
Azimuth	Degrees (W to S)	0
Ground Reflectance	%	20
Tracking System	-	No tracking

Wind turbine

A wind turbine is a rotary device which is designed to extract energy from the wind. For this analysis, WES 5 Tulipo type upwind turbine with variable speed synchronous generator and IGBT converter is considered to produce electricity. The output power curve of the turbine has shown in Figure 5. For a low wind speed area like Kuakata, the selected turbine is appropriate due to its low cut in speed. The cut in speed is the lowest wind speed below which the wind turbine cannot produce power. To install selected wind turbines, the initial cost is 3,50,000Tk/ turbine is considered whereas the replacement charge is 3,00,000 Tk/turbine and the operation and maintenance cost is 3,000 Tk/turbine/year. Some of the technical parameters for WES 5 Tulipo wind turbine are given in TABLE 2.

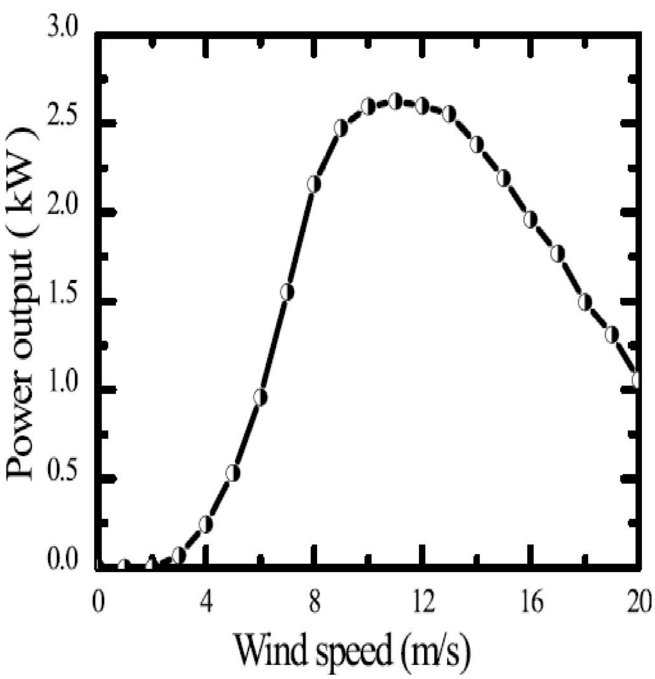

Figure 5 : The power curve of WES 5 Tulipo wind turbine.

TABLE 2 : The technical data related to the WES 5 Tulipo wind turbine.

Criteria	Unit	Values
Rated Power	kW	2.5
Starting wind speed	m/s	3.0
Rated wind speed	m/s	11.0
Diameter	m	5
Cut-off wind speed	m/s	20
Blade	no.	3
Lifetime	Years	15
Hub Height	M	25

Battery

The device which converts the stored chemical potential into electrical energy is called electric cell. A combination of such one or more electrochemical cells, used to convert stored chemical energy to electrical energy is called battery. It is a very popular storage device for electrical energy. The Trojan L16P battery is considered as a storage device. The primary installation cost is 9,000 Tk/battery. The replacement and maintenance costs are 8,000 Tk/battery and 500 Tk/battery/yr are included in the analysis. Some of the technical data for Trojan L16P battery are shown in TABLE 3.

TABLE 3 : The technical parameters for a Trojan L16P battery.

Criteria	Unit	Values
Nominal capacity	Ah	360
Nominal voltage	V	6
Round trip efficiency	%	85
Minimum state of charge	%	30
Float life	yrs	10
Max. charge rate	A/Ah	1
Max. charge current	A	18
Lifetime throughput	kWh	1075
Suggested value	kWh	1180
Nominal capacity	Ah	360

Converter

A converter is a device which converts an electrical signal from alternating current (AC) to direct current (DC) or vice-versa. A converter can be an inverter, rectifier or both. A PV module produces DC and wind turbine produces AC to serve AC load. So, to synchronies these signals for charging as well as supply to the load, a converter is very essential for a hybrid system which comprises both wind and solar resources. The estimated primary installation and replacement costs are 14,933 Tk/kW and 10,000 Tk /kW respectively for the converter. Technical parameters for the inverter and rectifier module are furnished in TABLE 4.

TABLE 4 : Technical parameters for the inverter and rectifier module.

Criteria		Unit	Values
Inverter	Lifetime	Year	15
	Efficiency	%	90
Rectifier	Capacity relative to inverter	%	100
	Efficiency	%	85

RESULTS AND DISCUSSION

Maximum annual capacity shortage

The maximum annual capacity of shortage is the maximum allowable value of the capacity shortage fraction which is the ratio of the total capacity shortage and the total electric load over the year. In order to maintain 0% capacity shortage, the simulation will size the system to meet even this very high peak load. This could mean that the system has to include large, expensive equipment that is not fully used most of the time. Therefore, a lot of excess energy will be dumped due to lack of adequate load. It can raise the NPC which means the costs of installing and operating the system over its lifetime. Moreover, the capacity shortage is not desired for any system. But the advantage of the capacity shortage is that sometimes, it can reduce the NPC, as well as the LCOE drastically. The COE means the average cost per kWh of useful electrical energy produced by the system.

Figure 6 shows that the NPC decreases rapidly with increase of maximum annual capacity shortage, which becomes more significant as load size increases. But, beyond this, the NPC does not vary significantly with capacity shortage. On the other hand, the proposed system is designed for only domestic purpose and no critical load, which requires continuous power supply, is considered in the system. Therefore, a minimum 5% annual capacity shortage can be introduced without vacillation to make the system economically viable.

Optimum options

The LCOE for PV-battery system is very high compare to the optimize systems. Generally, a stand alone PV-battery system is not feasible in any context where 24 hours electricity demand is involved, because solar resource is not adequate to serve continuous demand for a locality. It is the fact that the daily average sun shine hour at Kuakata is nearly about 6.62 hours[31]. Therefore, energy can be extracted from sun for only 6.62 hours/day. During rainy season several consecutive cloudy days may appear which enlarge the size of the battery bank and causing the system very expensive and uneconomic. Conversely, energy might be ex-

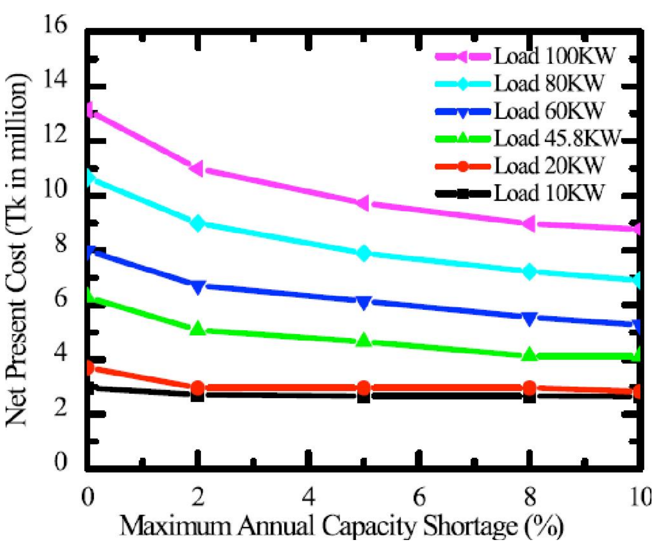

Figure 6 : Relation between NPC and maximum annual capacity of shortage.

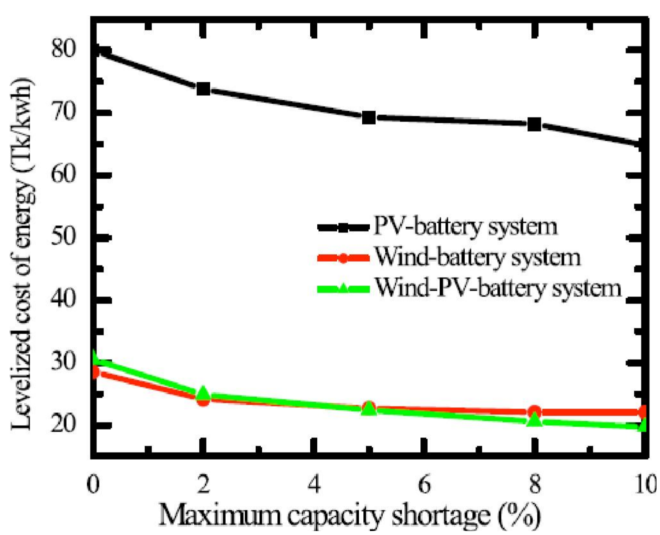

Figure 7 : The effect of maximum annual capacity shortage on LCOE.

tracted from wind all over the day and when it is working simultaneously among with the solar energy and storage device a reliable supply of electricity will be established. This can reduce the NPC as well as the COE drastically which is shown in Figure 7.

Figure 7 shows that the COE of the PV-battery system is very high compare to the wind-battery or wind-PV-battery system. Consequently, the wind-battery or wind-PV-battery is more feasible than the PV-battery system. On the contrary, below the load of about 50 kW, a wind-battery system is more economic than a wind-PV-battery system. But beyond this load, a wind-PV-battery system is an economically feasible system.

Optimum load size

To find an optimum load size the LCOE is used rather than the NPC as the NPC increases with increase in load size but the LCOE decreases with increase in load size. A renewable energy based power plant is not feasible for a very small load size. Starting from an undersized load, the LCOE is decreased with load. Figure 8 shows that the threshold load for the proposed site is nearly about 50kWh/d, which indicates the optimized load must be greater than 50kWh/d to become a system economically feasible system with an annual capacity of shortage 5%.

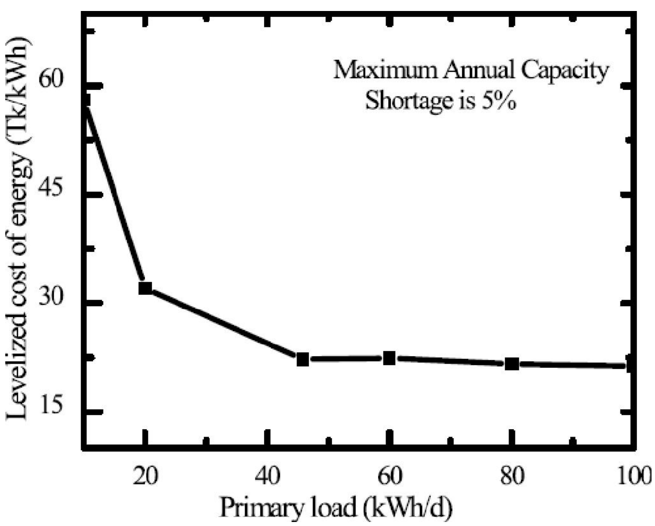

Figure 8 : The effect of primary load on LCOE.

Excess energy

The excess energy means the additional energy that cannot be used by the system. The system is configured in such a way that it can deliver power constantly. But the load demand is not fixed and it varies with time and season. Figure 9 shows that the excess energy is lowest for 60 kWh/d load demand. Therefore, it is appropriate to serve power for a minimum load size of 60 kWh/d. Analysis shows that, in this case, the excess electricity is 16,629 kWh/yr and 39.6% of the total production. Again the excess energy can be minimized by introducing some capacity of shortage. This shortage will make some load shedding at peak hour and minimize the excess energy. The system is configured for supplying the load at the peak hour. Therefore, the excess energy is produced at the off-peak hour and this energy might be dumped due to lack of demand.

The main disadvantage of the excess energy is that it may increase the system size as well as the COE. This excess energy can be reduced by load matching and/or including some capacity shortage. For this reason, the excess energy should be minimized to make an economically feasible system.

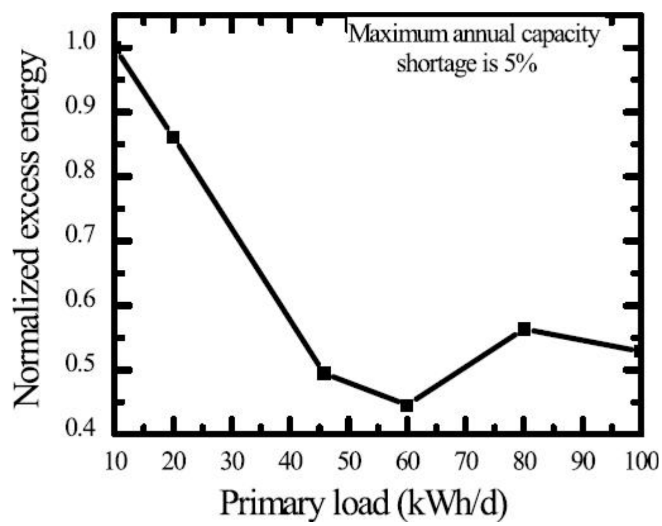

Figure 9 : The effect of primary load on normalized excess energy.

Cost analysis for the optimized system

From the optimum load size analysis, it is evident that 60kWh/d is the minimum load size with an annual capacity shortage of 5% and the wind-PV-battery hybrid system is the most economically feasible option. The optimal type of system combines PV array of 5 kW and 5 pieces of WES 5 Tulipo wind turbines. Besides these, 90 pieces of Trojan L16P battery and 15 kW converter are used as storage and conversion de-

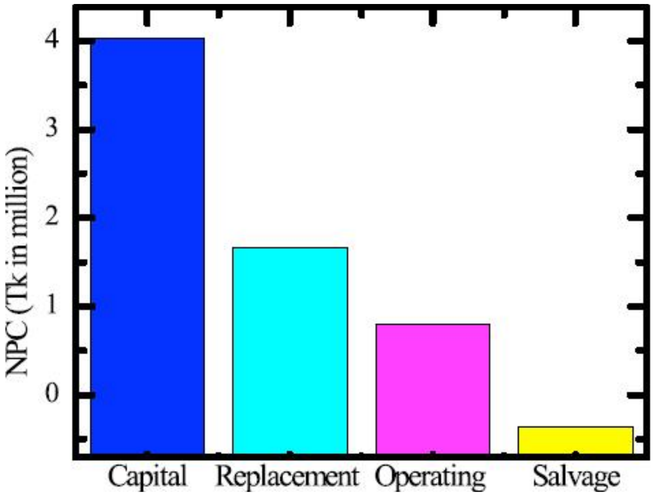

Figure 10 : The cash flow summary for the optimized hybrid system.

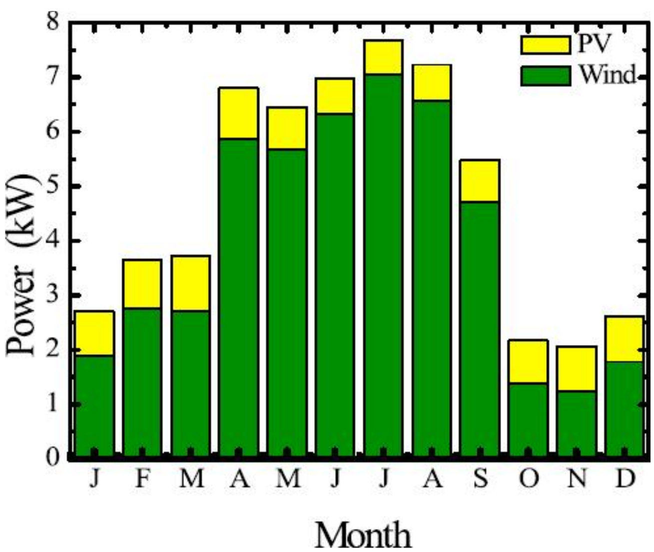

Figure 11 : Monthly average electricity production by PV and wind.

vices receptively. In this case, the initial capital is 40,33,995Tk and the operating cost is 7,98,960 Tk/ yr. Therefore, the total NPC is 61,38,614Tk and the COE is 22.43 Tk/kWh considering an annual capacity shortage of 5%. The cash flow summary of the proposed hybrid system is illustrated Figure 9. The maximum cost for such a system is due to primary installation cost. It is perceptible here that this system has no fuel cost and low maintenance cost. The replacement cost is less than 50% compared to the primary installation charge. Therefore, in the long run it is an economically viable system if it will not damage physically. The energy yield from different components of wind-PV-battery system with load size 60kWh/d is revealed in Figure 11. In such a hybrid system the wind turbine contribution would be 90% and 10% of the electricity would come from PV panels. For a mini-off-grid system, LCOE decreases as the village size increases. Comparing the results for home systems with different load sizes suggest that the minimum economical scale for the mini-off –grid wind-PV-battery system can be found for load size at least 25 households (50kWh/d) and probably higher for the proposed site.

Comparison with grid

It is obvious that a stand-alone renewable energy based power plant is more economic than the grid extension in the case of remote off-grid area because extension of grid is expensive and functions of distance. But the NPC of a hybrid system is not a function of distance. The initial capital cost of the grid extension is 1,00,030 Tk/km, the annual cost of maintaining the grid extension is 20,020 Tk/yr/km (Bangladesh Power Sector) and the price of electricity from the grid is 3.00Tk/ kWh are considered to calculate the break even grid extension distance which is the distance from the grid which makes the NPC of extending the grid equal to the NPC of the stand-alone system. Figure 12 shows the relation between the NPC and grid extension distance for the optimized hybrid system. It is evident that the break-even distance is about 15 km for a hybrid system consuming 60kWh load daily. It means that the hybrid system is economically feasible when the locality is situated at a distance of about 15 km or more

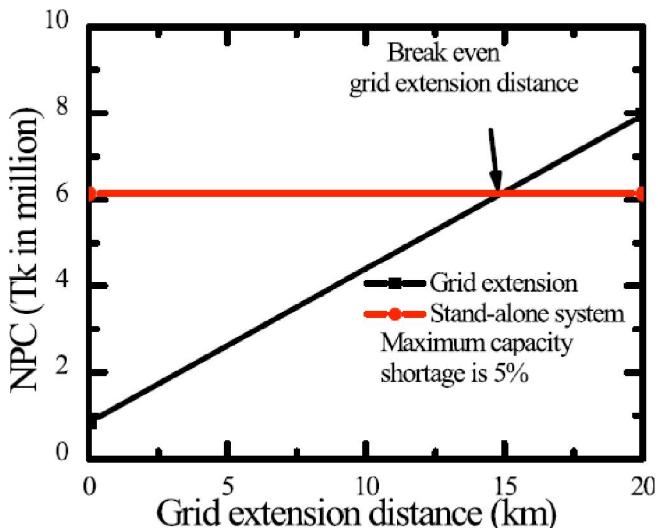

Figure 12 : Electrification cost for the grid extension and a standalone hybrid system.

from the grid. It is also noted that this distance is measured if the existing grid is extended through a flat inland area. But in Kuakata, there are some small rivers and cannels which indicate that the grid extension and maintenance over a river is very costly. Therefore, an optimized PV-wind-battery hybrid system would be a convenient power extracting system at the proposed place.

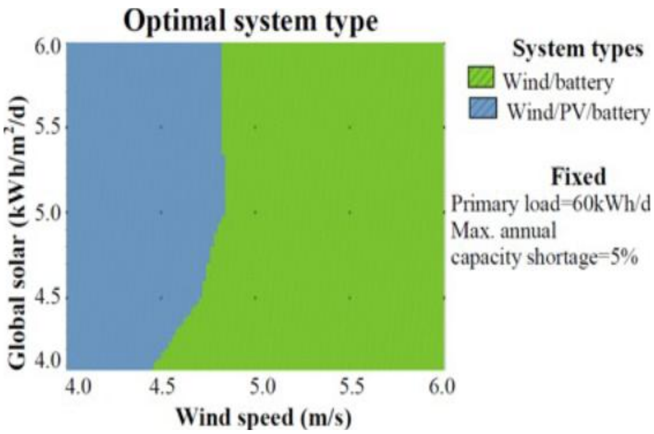

Figure 13 : Optimized hybrid system for 60 kWh/d load and maximum 5% annual capacity shortage.

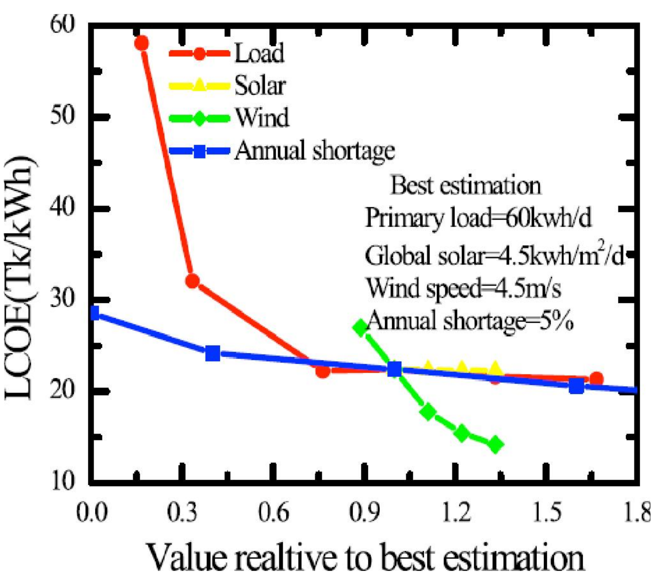

Figure 14 : Sensitivity of LCOE on solar radiation and wind speed.

TABLE 5 : Different sensitivity cases.

Sensitivity	Unit	(1)	(2)	(3)	(4)	(5)	(6)
Daily load	kWh/d	10	20	45.8	60	80	100
Global Solar Radiation	kWh/m^2/day	4	4.5	5	5.5	6	-
Wind Speed	m/s	4	4.5	5	5.5	6	-
Max. Annual Capacity Shortage	%	0	2	5	8	10	-

Sensitivity analysis

A sensitivity variable is an input variable for which multiple values have been specified. A separate optimization procedure for each specified value is performed, which is called the sensitivity analysis. Sometimes it is useful to see how the results vary with changes in inputs, either because they are uncertain or because they represent a range of applications. The flow of wind and solar irradiance are not a constant phenomena and it changes every instant. Therefore, the exact values of wind speed and solar radiation might be uncertain. Furthermore, the sensitivity analysis should be considered for load consumption and maximum annual capacity shortage to get an economically viable system. For each sensitivity case, HOMER searches the least cost system in their respective search space and in this analysis it simulates 10080 individual systems and 750 sensitivity cases for each system configuration. The considered sensitivity cases are enlisted in TABLE 5.

The optimization result in terms of wind speed and global solar radiation for a group of people consuming 50kWh/d with an annual capacity of shortage maximum 5% capacity shortage is depicted in Figure 13, represents a particular system is optimized for a certain combination wind speed and global solar radiation. When the wind speed is about 4.7 m/s or more and the global solar radiation is about 4.5 m/s or more, then a wind-battery system is feasible. Otherwise, a wind-PV-battery hybrid system becomes economically feasible. It is worth noting that the configurations of the feasible system dependents on the wind speed.

Figure 14 demonstrates variation of various sensibilities like primary load, solar radiation wind speed and capacity shortage. Here the sensitivity curve of wind is stiffer than that of other variables. It means that the wind speed is strongly depending on the LCOE compare to any other variable. In contrast, the contribution of solar energy has a little effect on the LCOE.

Pollutant reduction

A hidden cost, which is not taken into consideration while using fossil fuels, is paid by human beings. Fossil fuels based plants produce a huge amount of GHGs. The GHGs emitted per MWh energy production from some typical fuels which are frequently used in conventional power plants are shown in TABLE 6

TABLE 6 : GHG emission factors for some conventional fuels.

Fuel Type	CO_2 emission factor (Kg/GJ)	CH_4 emission factor (Kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t-CO_2/ MWh)
Natural gas	5.61	0.0030	0.0010	45.0	0.0	0.452
Large hydro	00.0	0.0000	0.0000	100.0	0.0	0.000
Diesel	74.1	0.0020	0.0020	30.0	0.0	0.897
				Electricity mix		0.465

Global warming potential of GHG; 1t CH_4 = 21 t CO_2; 1t N_2O = 310 t CO_2

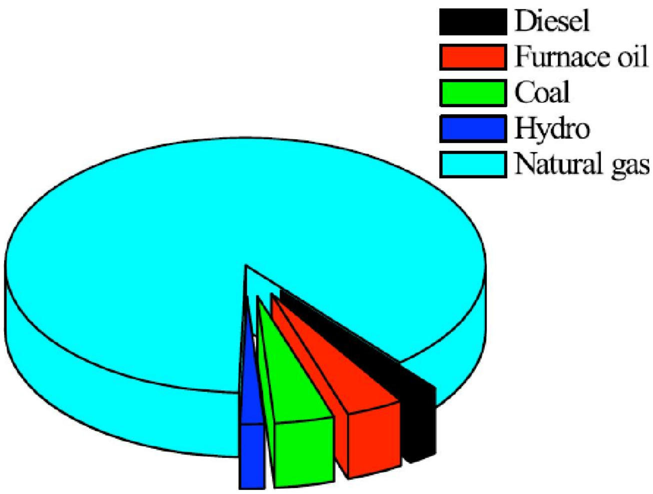

Figure 15 : Power generation pattern of the grid electricity (FY 2009).

(IPCC, 1996)[32]. The generation pattern of the grid electricity (BPDB, 2010) from various sources in Bangladesh is shown in Figure 14.

Figure 15 shows that the maximum power plants in Bangladesh are run by the fossil fuel for electricity generation. These types of power plants produce an enormous amount of GHGs like CO_2, N_2O, CH_4 etc. They have a negative impact on the lower level of the atmosphere. Basically these types of gases are responsible for the global warming and the hole in the ozone layer. To save the atmosphere and prevent the change of climate, these types of gases must be controlled in the atmosphere. In this study, the proposed power plant is 100% renewable energy based and no way to release GHG to the atmosphere. The optimum power plant is able to produce electricity of about 42.03MWh/yr. If the power plant is replaced by the grid connection which is basically run by the conventional fuel, around 20 t CO_2/yr may be added to the atmosphere. Therefore, this enormous amount of CO_2 might be mitigated from the atmosphere by using the renewable energy based power plant.

CONCLUSION

The study performed the possibility of a wind-PV hybrid system which is 100% green power plant to meet the energy demand of a rural community consuming 50kWh/d for at Kuakata in Bangladesh. Through this analysis, we show that a wind-PV-battery off-grid power plant is more economic than a stand-alone wind or PV system. This system is feasible in those remote areas in Kuakata which are located at a distance of about 15 km or more from the existing grid supply. In the proposed system the energy is extracted from wind is 83% and remaining from the solar energy. Green house gases emission calculation of the proposed community showed that about 20 t CO_2 can be mitigate from the atmosphere. This research indicates that the available renewable resources at Kuakata are significant and that a hybrid power system would be feasible for the site.

NOMENCLATURE

AC	Alternating current
COE	Cost of energy
DC	Direct current
GDP	Gross domestic product
GHG	Green house gas
LCOE	Levelized cost of energy
LGED	Local government and engineering department
NPC	Net present cost
STC	Standard test condition
a, b	Regression coefficients
c	Scale parameter (m/s)
f_{pv}	PV derating factor (%)
$f(v)$	Weibull function

G_T	Solar radiation incident on the PV array in the current time step (kW/m^2)
$G_{T'STC}$	Incident radiation at standard test conditions (kWh/m^2)
H_c	Average clean sky daily radiation on a horizontal surface (kWh/m^2)
H_g	Monthly average daily global radiation (kWh/d)
H_o	Monthly average of the daily extra terrestrial radiation (kWh/d)
k	Shape parameter
K_T	Clearness index
S	Mean monthly average daily sun shine hour (h)
S_O	Maximum possible sun shine hour (h)
T_C	PV cell temperature in the current time step (°C)
$T_{C'STC}$	PV cell temperature under standard test conditions (25°C)
Y_{pv}	Rated capacity of the PV array output under standard test conditions (kW)
αp	Temperature coefficient of power (/°C)
Γ	is the gamma function
ω_S	Hour angle (degree)

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