Final Report

Feasibility and Integration of Wind Energy into Solar Mini-Grid at Monpura Island

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Abbreviations

BAEC	Bangladesh Atomic Energy Commission
BCAS	Bangladesh Center for Advance Studies
BCSIR	Bangladesh Council for Scientific and Industrial Research
BOP	Balance of Plant
BPDB	Bangladesh Power Development Board
BRAC	Bangladesh Rural Advancement Committee
DTU	Technical University of Denmark
ESMAP	Energy Sector Management Assistance Program
GEF	Global Environment Fund
GHG	Green House Gas
GWA	Global Wind Atlas
GOB	Government of Bangladesh
GTZ	German Organization for Technical Cooperation
IFC	International Finance Corporation
IDCOL	Infrastructure Development Company Limited
KII	Key Informant Interview
kW	Kilo Watt
kWh	Kilo Watt hour
kWp	Kilo Watt Peak
LGED	Local Government Engineering Department
LiDAR	Light Detection and Ranging
MW	Mega Watt
MWh	Mega Watt hour
NREL	National Renewable Energy Laboratory (USA)
O&M	Operation and maintenance
PV	Photovoltaic
RE	Renewable Energy
SHS	Solar Home Systems
SMG	Solar-diesel Hybrid Mini-grid
SRE	Sustainable Rural Energy
SREDA	Sustainable and Renewable Energy Development Authority

SREPGen	Development of Sustainable Renewable Energy Power Generation
SWERA	Solar and Wind Energy Resource Assessment
UNDP	United Nations Development Program
VRE	Variable Renewable Energy
WASP	Wind Atlas Analysis and Application Program
WREL	Western Renewable Energy Limited
WEC	Wind Energy Converter
WMG	Wind Minigrid
WT	Wind Turbine

Preface

There are a number of solar-diesel hybrid mini-grids with battery storage that has already been implemented at various off-grid locations of Bangladesh and many are on the way. The mini-grid experience so far has revealed a few important aspects, such as the difficulty of maintaining the battery storage, the associated expenses, and the losses associated with the repeated charging and discharging cycles of the battery etc.

Integration of wind energy converters into the solar-diesel powered hybrid mini-grid has the potential to address the issue of battery storage along with a multitude of other benefits. Since in many cases the wind and solar energy tend to complement each other, the battery requirement will be reduced at least to some extent. The integration will also reduce the losses and lower the tariff as well by cutting down the huge cost component typically associated with battery storage. Another important benefit is that by integrating a wind converter into a solar-diesel mini-grid located on a sea-island, the yet untapped wind resource can be exploited.

However, since such integration projects are still at a very early stage of implementation in Bangladesh, decisions shall be backed by a number of preliminary investigations covering topics like available resources and technologies, financial landscape, risk analysis etc. This study aims to support the Ministry of Power, Energy and Mineral Resources (MPEMR)/SREDA in examining various aspects associated with wind converter integration projects. It includes detailed assessment of available wind resource, estimation of approximate monthly and annual energy yield, day and night energy yield calculations, cost breakdown, possible financing structures, recommended procurement process, associated risks, typical operation and maintenance procedure of wind energy projects etc.

1 Introduction

1.1 Background

The significance of ensuring universal access to sustainable energy has already been well established as a precondition to global development and mitigating climate change across the globe, particularly among the developing nations. According to the World Bank, as of 2016, approximately 12.65% of the world population did not have access to electricity, which translates into approximately 0.92 billion people [1]. But the challenge is not only to avail electricity to this 0.92 billion people, but to provide them with "affordable, reliable, sustainable and modern" form of it [2].

In line with the global consensus on the importance of moving towards sustainable means of power production, the Government of Bangladesh (GoB) has taken several initiatives to decarbonize the energy sector. Over the last decade, their notable efforts have been undertaken in the energy sector development:

(a) increasing the total generation capacity,

(b) expanding the national grid network, and

(c) diversifying the energy mix to ensure energy security.

All these efforts are being realized in the context of the following noteworthy targets set by the GoB.

- The Power Division of Government of Bangladesh aims to provide quality electricity for all Bangladeshis by 2021 "through integrated development of power generation, transmission and distribution network" [3];
- Sustainable and Renewable Energy Development Authority (SREDA) has declared the aim to support the GoB in producing 10% of the total electricity from renewable sources by the year 2020 [4]; and
- Infrastructure Development Company Limited (IDCOL) has launched its Renewable Energy program to support the propagation of renewable energy-based projects all across the country on a massive scale.

In the above context, as of June, 2018, IDCOL has installed nearly 4.13 million Solar Home Systems (SHSs) [5]. With grant and fund support from various development partners, IDCOL has also implemented 18 solar PV off-grid mini-grids with diesel gen-set backup as of November 2018. There are another 10 mini-grids under construction or at different stages of approval [6]. Altogether, IDCOL has set a target to implement 50 mini-grid projects by 2018 and 200 by 2021 [6, 7].

However, the consensus among the public and private sectors is that the GoB's renewable energy target cannot be achieved solely by utilizing solar PV for electricity.

Moreover, recent experiences in implementing off-grid mini-grids revealed the challenges of maintaining the costly equipment of the mini-grid system, including the energy storage systems. Convenient electrical storage systems such as batteries have become the integral part of an off-grid mini-grid solution as solar radiation, the source of energy is available only during the day.

Considering the need for storage and the challenges in maintaining the mini-grid system, it is essential to investigate the potential for wind energy utilization in Bangladesh in further detail. Wind resource has been underutilized in Bangladesh, until now. There has not been even any significant effort to assess the potential. A feasibility study would demonstrate that the coastal belt of Bangladesh can be considered as a prospective wind power extraction region. The GoB has already started implementing solar-diesel mini-grid project in some of the remote coastal islands that are inhabited by people. Integrating wind turbines into these solar mini-grids can be beneficial from the following aspects:

- Solar energy is available only during the day. On the other hand, diurnal characteristics of wind speed indicates that wind turbines typically tend to produce higher energy during the night, often resulting in complementing profiles [8].
- Integration of wind turbine can potentially reduce the battery storage requirement and therefore can reduce the cost of energy (i.e., tariff) as well.
- The cost of wind power technology is showing a downwards trend in the global market [9].

This report aims to address the issue of integrating wind energy into the overall energy scenario of Bangladesh. It is prepared as part of the Global Environment Fund (GEF) funded "Development of Sustainable Renewable Energy Power Generation (SREPGen)" project, implemented by the Power Division operating under the Ministry of Power, Energy and Mineral Resources (MPEMR) of the Government of Bangladesh.

More specifically, the report will aim to study various aspects related to the integration of a 100 kW wind turbine into the solar mini-grid at Monpura Island, Bhola. The island, with an area of 373 km^2, is located in the southern coastal region of Bangladesh and is inhabited by 67,304 people as per the census of 2001 [10]. Figure 1 shows the geographical location of the Monpura Island [10]. At present, some of the people living in the island are already benefitting, both socially and economically, from the electricity produced by the existing solar-diesel mini-grid. If implemented effectively, integrating a wind turbine into the solar-diesel system has the potential of increasing renewable share of the electricity production, reducing the need for batteries, and reducing the tariff.

Figure 1: Geographical location of Monpura Island.

1.2 Objective of the work

The broader aim of the SREPGen project is to reduce the annual growth rate of GHG emissions from fossil fuel-based electricity generation system by utilizing Bangladesh's renewable energy resource for electricity. Support will be provided to SREDA through this project to increase the share of renewable energy in the country's energy mix by promoting its widespread use. This report is prepared with the aim of assisting SREDA to develop technical and financial solutions for integrating a wind energy converter and battery backup with solar PV mini-grids.

1.3 Scope of the work

The scope of this assignment under the SREPGen project includes the following aspects:

- Mapping of wind energy related works conducted in Bangladesh;
- Assessment of wind energy generation at Monpura Island from available secondary data;
- Conduct Key Informant Interviews (KII) on the implementation of wind energy converter at Monpura;
- Prepare an estimated cost for integrating a 100 kW wind energy converter into the solar mini-grid at Monpura;
- Justification of suitable grant fund for integrating wind energy converter (WEC) in solar mini-grid [pilot basis];
- Recommend a procurement process for the integration of WEC at Monpura;
- Prepare an operation and maintenance plan for the project sponsor to ensure satisfactory plant performance; and
- Prepare a list of key project implementation risks and issues and propose viable mitigation measures.

2 Wind energy mapping in Bangladesh

This section discusses various initiatives on wind energy mapping in Bangladesh on the basis of primary resource data collection, data availability and notable wind energy projects in the country.

2.1 Primary data collection related works

A literature survey of wind energy related works in Bangladesh reveals that so far there is a general lack of efforts in this sector. A few attempts were made in the past to measure and analyze the primary wind resource data in terms of wind speed. Data collected by Bangladesh Meteorological Department (typically measured at 5-10 m height [11, 12]) is primarily intended for weather forecast and therefore not sufficient to estimate wind energy potential at any particular location [13]. Some of the other attempts are provided in the Table 1 below [14, 15]:

Table 1: Summary of primary wind speed data collection initiatives in Bangladesh.

Organization	**Location**	**Anemometer height** (m)	**Average speed** (m/s)	**Measuring period**
Bangladesh Center for Advance Studies (BCAS)	Kuakata	25	4.50	September 1996 – August 1997
	Charfassion	25	4.00	
	Noakhali	25	2.90	
	Chittagong	25	3.80	
	Kutubdia	25	4.40	
	Cox's Bazar	25	3.20	
	Teknaf	25	2.80	
Bangladesh Council for Scientific and Industrial Research (BCSIR)	Teknaf	10	3.50	January 2001 – April 2002
	Saint Martin's	30	4.70	
German Organization for Technical Cooperation (GTZ)	Feni	20	4.00	June 1996 – May 1997
	Anwara	20	4.40	
	Teknaf	20	4.30	
Bangladesh Atomic Energy Commission (BAEC)	Patenga	20	6.57	February 1995 – January 1996
	Cox's Bazar	20	6.06	
	Companygonj	20	6.23	
	Kuakata	20	6.36	

Sustainable Rural Energy (SRE) and Local Government Engineering Department (LGED)	Kutubdia	20	3.72	June 2005 – December 2006
	Khagrachari	20	3.32	
	CUET	20	2.30	
	Kuakata	30	4.23	

The primary wind speed data collection initiatives listed in Table 1, suffer from several limitations, including unreliability of the data. Several researchers cited the following limitations: comparatively lower anemometer height, existence of considerable surface roughness and surrounding obstacles, poor data recording mechanisms, and that the locations are dispersed locations. Apart from the measurement efforts mentioned in Table 1, the final report of Solar and Wind Energy Resource Assessment (SWERA) has presented the outcomes of wind speed prediction along the coast using Wind Atlas Analysis and Application Program (WAsP) [16].

Despite the lack of long-term, geographically denser, locally available and readily usable primary wind speed data, researchers have attempted to analyze the wind resource based on the listed datasets and various global databases [11]. Some of the usable global databases of wind resources are as follows:

i. Surface meteorology and Solar Energy (SSE) and National Aeronautics and Space Administration’s (NASA) Earth Science Enterprise Program database;
ii. Climate Diagnostic Center (CDC) database by National Oceanic and Atmospheric Administration (NOAA) and Cooperative Institution for Research and Environmental Sciences (CIRES);
iii. Online database by National Renewable Energy Laboratory (NREL) Geospatial Data Science team [17]; and
iv. Global Wind Atlas (GWA 2.0) [18].

Among these four sources, the NREL and GWA provides access to the recent wind speed map (geographical data) of Bangladesh at free of cost. Very recently, NREL has published a report on the outcomes of long-term wind speed data measurement at 7 different locations of Bangladesh [19]. However, to confidently calculate annual energy yield from wind energy converters, at least hourly data is required, which, at present, is available from GWA for only one location in Bangladesh (at a location in Feni) [20]. Considering the readiness of data availability, closeness to the project location and availability of hourly data have led to the utilization of the hourly data at Feni from GWA for all the calculations in this study.

The consensus in the literature is that the coastal regions of Bangladesh enjoy comparatively higher wind speed than further onshore. Therefore, it is reasonable to conclude that wind energy extraction plants shall be planned along the coastal belt in the southern part of the country.

2.2 Wind energy extraction attempts

There have been only limited attempts to extract wind energy in Bangladesh. The history of wind power projects in Bangladesh can be traced back to 2005. Only two projects, each having a nominal capacity of ~1 MW, have been implemented so far by the Bangladesh Power Development Board (BPDB). Details of these two projects are provided in Table 2 [21].

Table 2: Details of two notable wind power projects in Bangladesh.

Details	**Location**	
	Muhuri Dam, Feni	**Kutubdia, Cox's Bazaar**
Type	On-shore	On-shore
Nominal power	4 * 225 kW	50 * 20 kW + 20 * 50 kW
Turbine manufacturer	Vestas (Model: V27/225)	Information not available
Grid connectivity	On-grid	Off-grid with battery storage
Commissioning year	2005	2008 (1 MW); 2015 (1 MW)
Operator	BPDB	BPDB
Coordinates	22°50'8" N, 91°26'53" E	21°46' 58" N, 91°50'52" E

A few sources (including journals and articles) have reported the installation of smaller wind turbines by various government bodies and NGOs at various other locations spread across the coastal region. Most of these projects date back as early as 1997; however, updated information on the current status of these projects is not readily available. Table 3 lists the details of some notable small-scale projects in Bangladesh [13, 22]:

Table 3: Small-scale wind projects in Bangladesh.

Organization	**Location**	**Details**
Grameen Shakti	Chakoria, Chittagong	1 kW, Shrimp Farm
Grameen Bank	Charduani, Barguna	3*1.5 kW and 1*7.5 kW, Cyclone Shelters
BRAC	Coastal Area	11 small turbines
LGED	Tangail, Cox's Bazar etc.	8.5 m high wind-pumps
BCAS	Patenga, Chittagong	12 high wind-pump

Apart from the initiatives discussed here, several other wind power projects along the coastal region are either on-going or being planned. The projects are of utility scale with installed capacities above 1 MW. **Error! Reference source not found.** lists the planned ind power projects [21].

Table 4: Planned and under implementation wind power projects in Bangladesh.

Location	Details	Status
Sirajganj, adjacent to the river erosion protection dam of Bangabandhu Bridge (Jamuna Multi-purpose Bridge)	2 MW, BPDB, on turnkey Basis	Under implementation
Cox's Bazaar	60 MW, grid-tied, IPP by US-DK Green Energy (BD) Limited	PPA signed
Anwara, Chittagong	100 MW, a Consortium of PIA Group LLC, Spain and Bangladesh Alternative Energy Systems Limited	LoI has been issued
Feni	30 MW, grid tied, IPP by Consortium of Regen - Siddhant Wind Energy Private Limited, India	Approval stage

3 Energy yield calculation

One major obstacle in developing wind power projects in Bangladesh is the lack of availability of reliable, geographically dense and long-term wind resource data. Suitable wind resource data at desired hub height (~50 to 60 m) at Monpura Island, Bhola is not readily available. Therefore, annual energy yield is calculated based on secondary data available for the nearest location at Feni [20].

3.1 Reference wind energy data source

Energy yield calculations in this report is based on the secondary data sources available online. Among the available data sources, the most updated information is available from NREL and GWA 2.0. Both sources provide geographical mapping of onshore and offshore wind speed in Bangladesh. However, to better understand the diurnal and seasonal variations in wind speed and resulting energy yield, at least hourly data is preferred, which is not available from NREL. On the other hand, the World Bank provides access to wind speed data generated by GWA 2.0 only at a nearby location in Feni [20].

The GWA 2.0 project is a result of the partnership between the Department of Wind Energy at the Technical University of Denmark (DTU) and the World Bank Group[1]. The project was primarily funded by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank and supported by 13 official bilateral donors.

The GWA 2.0 wind speed data is measured using a Light Detection and Ranging (LiDAR) measurement system at a location (22.80°N and 91.358°E) in Feni at an interval of 10 minutes. The measurement has been initiated in 2017 and is on-going. So far, 53907 data points have been collected. In this analysis, annual energy yield was estimated by extracting 52444 data points between 01 August 2017 and 31 July 2018.

3.2 Interpretation of wind speed data of the nearest available location

The hourly average wind speed at 60 m hub height at a location in Feni, Bangladesh is illustrated in Figure 2. It should be noted that the line plot starts from August 2017, which is a summer month. The wind speeds are thus comparatively higher at the beginning with multiple spikes near the end. Wind blows comparatively slowly during the winter season at the location, as seen at the middle of the plot along the X-axis.

[1] Comprising the World Bank and the International Finance Corporation (IFC).

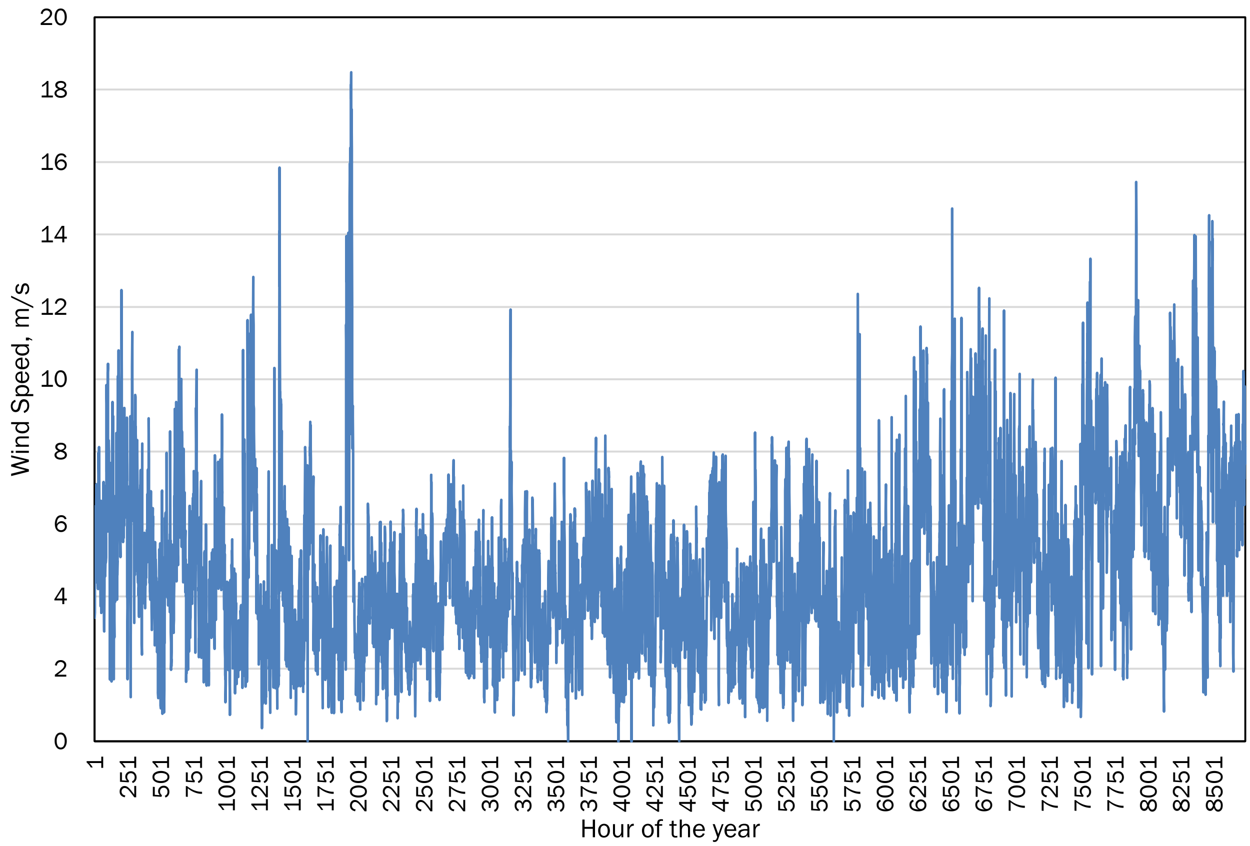

Figure 2: Hourly average wind speed at Feni at 60 m hub height

This trend is also supported in Figure 3 that shows monthly wind speed variation at Feni. This figure shows the monthly average, maximum and minimum wind speed. In terms of wind speed variation, it can be concluded that January and July can be considered as the off and peak month of energy yield respectively.

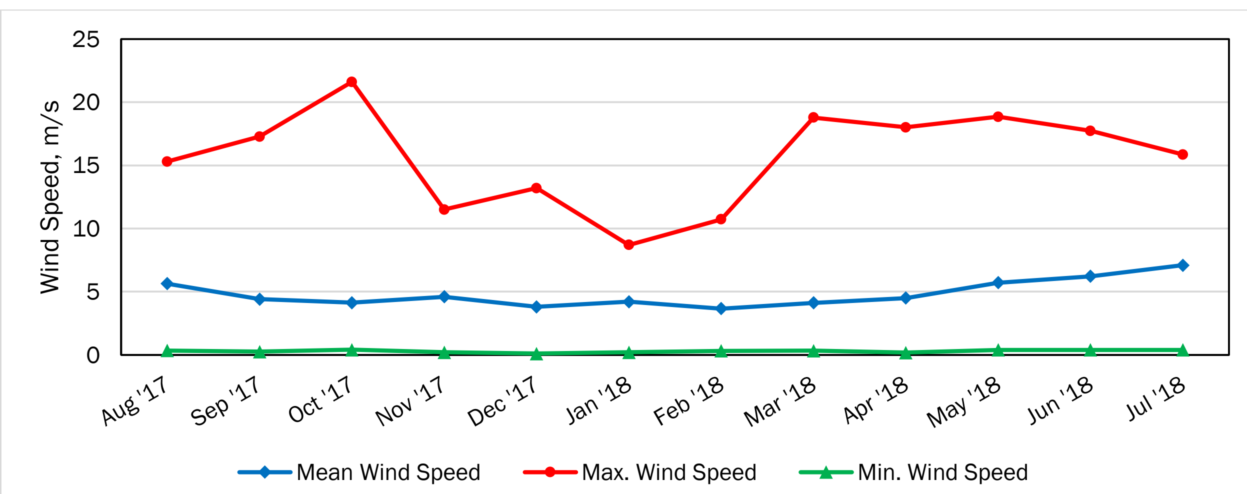

Figure 3: Monthly wind speed variation at Feni.

Daily wind speed profile for each month at 60 m hub height at Feni is illustrated in Figure 4 that demonstrates diurnal variations in wind speed. Data between August 2017 and July 2018 have been analyzed and hourly averages over a month are aggregated to create the daily wind speed profile. Wind speed during the day is different from the nighttime profile. In most months, nighttime wind speed is higher than during the daytime. The difference in wind speed during the day and night hours are more prominent during the winter season than that of the summer season. This is an advantage of integrating a wind-energy converter with a solar mini-grid as they can be complementary because greater wind energy is available during the night when there is no sunlight to generate electricity from solar PV systems.

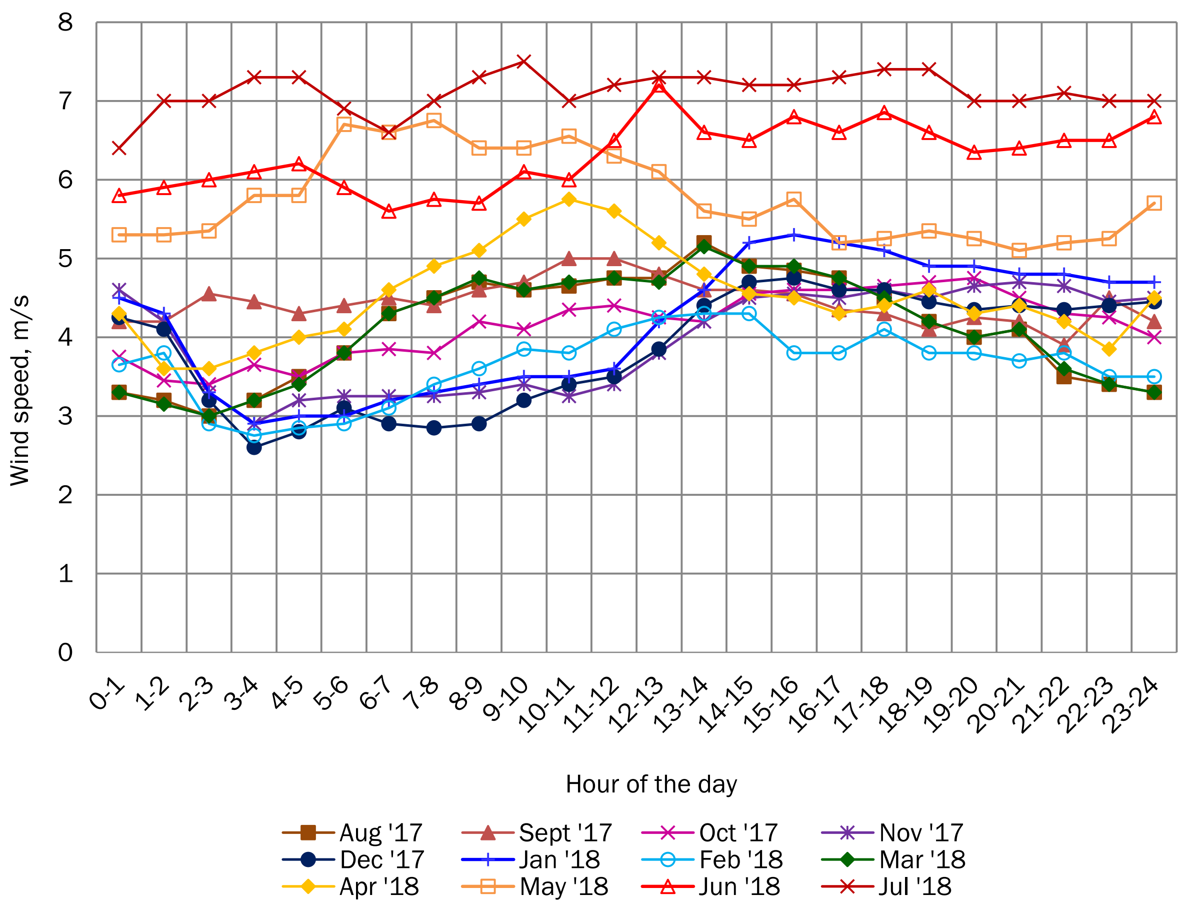

Figure 4: Daily wind speed profile for each month at 60 m hub height at Feni.

3.3 Annual energy yield calculation

The first step in annual energy yield calculation is to generate a wind speed histogram. The frequency of wind speed ranges is then used to generate the Weibull probability distribution. Figure 5 and Figure 6 show the calculated wind speed histogram and Weibull probability distribution at Feni. The histogram reveals that the wind speed ranging from 3 to 6 m/s have comparatively higher frequency. In the next step, the probability values along with the power output data provided by the wind turbine manufacturer is used to calculate the energy yield.

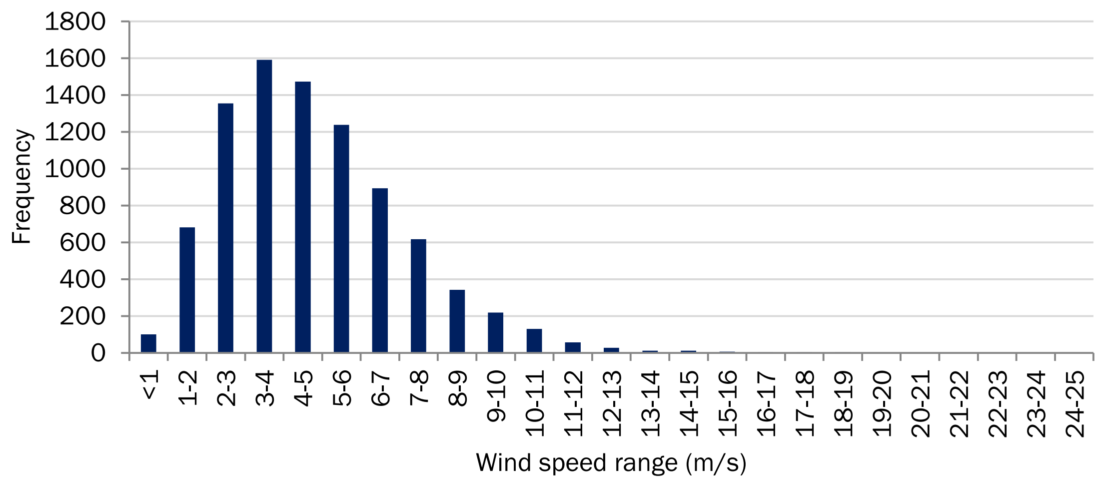

Figure 5: Wind speed histogram at Feni.

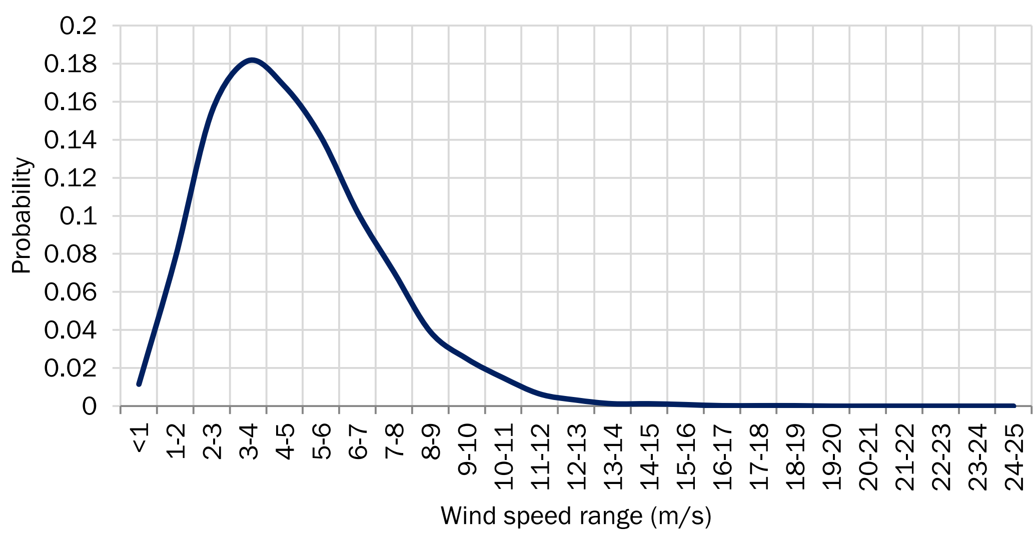

Figure 6: Weibull distribution of wind speed at Feni.

For the Monpura project, The power curve of commercially available wind turbine (Aeolos–H 100 kW WEC) of this size is provided in Figure 7.

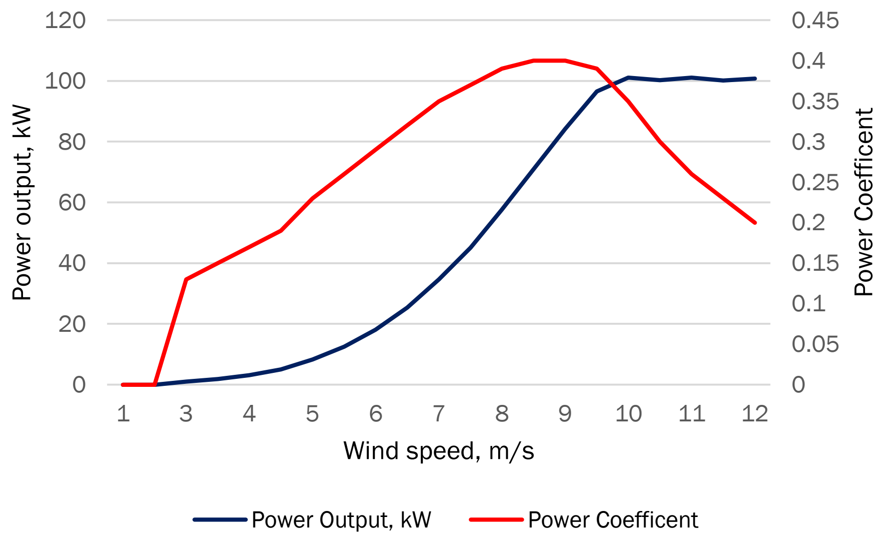

Figure 7: Power generation curves of the selected Aeolos–H 100 kW WEC.

Table 5 gives annual energy yield calculation from the selected Aeolos-H 100 kW wind turbine at Feni using 60 m wind speed data. Annual energy yield from the selected wind turbine is approximately 183.5 MWh. However, it is reasonable to assume that the value may include some uncertainty or calculation error. The main sources of error and calculation uncertainties are discussed in Section 3.6. However, for a feasibility study, this is a reasonably representative prediction, and should be considered for the purposes of the work.

Table 5: Annual energy yield from 100 kW wind turbine at Feni.

WIND SPEED	MEAN WIND SPEED (M/S)	NUMBER OF BINS	PROBABILITY	POWER, KW	HOURS IN YEAR	ENERGY YIELD, KWH
1	<1	101	0.01153	0	8760	0
2	1-2	682	0.077854	0	8760	0
3	2-3	1355	0.15468	1.01	8760	1368.55
4	3-4	1591	0.181621	3.14	8760	4995.74
5	4-5	1473	0.168151	8.3	8760	12225.9
6	5-6	1239	0.141438	18.09	8760	22413.51
7	6-7	893	0.101941	34.66	8760	30951.38
8	7-8	617	0.070434	57.66	8760	35576.22
9	8-9	342	0.039041	84.2	8760	28796.4
10	9-10	218	0.024886	101.06	8760	22031.08
11	10-11	130	0.01484	101.08	8760	13140.4
12	11-12	56	0.006393	100.79	8760	5644.24
13	12-13	28	0.003196	100.79	8760	2822.12
14	13-14	11	0.001256	100.79	8760	1108.69
15	14-15	11	0.001256	100.79	8760	1108.69
16	15-16	7	0.000799	100.79	8760	705.53
17	16-17	2	0.000228	100.79	8760	201.58
18	17-18	2	0.000228	100.79	8760	201.58
19	18-19	2	0.000228	100.79	8760	201.58
20	19-20	0	0	100.79	8760	0
21	20-21	0	0	100.79	8760	0
22	21-22	0	0	100.79	8760	0
23	22-23	0	0	100.79	8760	0
24	23-24	0	0	100.79	8760	0
25	24-25	0	0	100.79	8760	0
TOTAL ANNUAL ENERGY YIELD in kWh						183,493.2
TOTAL ANNUAL ENERGY YIELD IN MWH						183.5

The annual energy yield with respect to wind speed is given in Figure 8. The highest energy yield is for wind speed of 7-8 m/s.

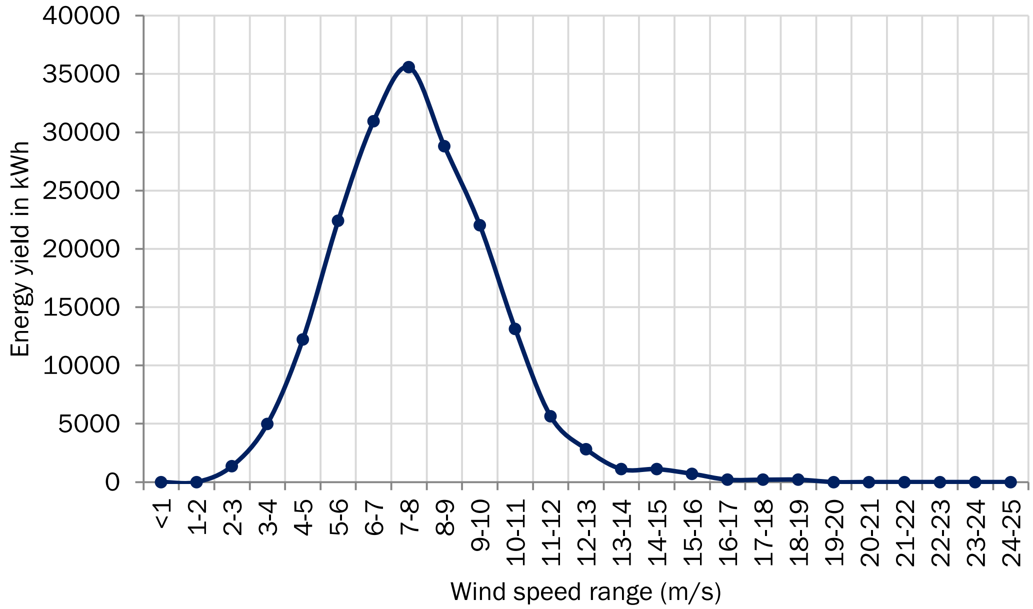

Figure 8: Annual energy yield vs wind speed at 60 m hub height at Feni.

It is also important to study the daily generation characteristics of the selected wind turbine. The following sections discuss the estimated daily energy yield during both off- and peak-season from the selected wind turbine. It is apparent from Figure 4 that the wind speed is usually lower in the winter season (from November to February) and comparatively higher during the summer season (April to August). These time periods can be considered as the off and peak season in terms of wind energy generation.

3.4 Daily energy yield during off-season (January, 2018)

As previously discussed in Section 3.2, January as an off-season month is characterized by low energy yield. Figure 9 shows daily average wind speed profile for January 2018. The diurnal variation in wind speed is apparent, with the lowest wind speed of 2.87 m/s occurring at 4 am and the highest of 5.36 m/s occurring at 4 pm. The length of day is shorter during winter months – between 7 am and 5 pm. Due to higher wind speed at night time, the corresponding energy yield is also higher. As a result, the additional energy generation from wind turbine is likely to reduce the need for battery storage in the solar mini-grid.

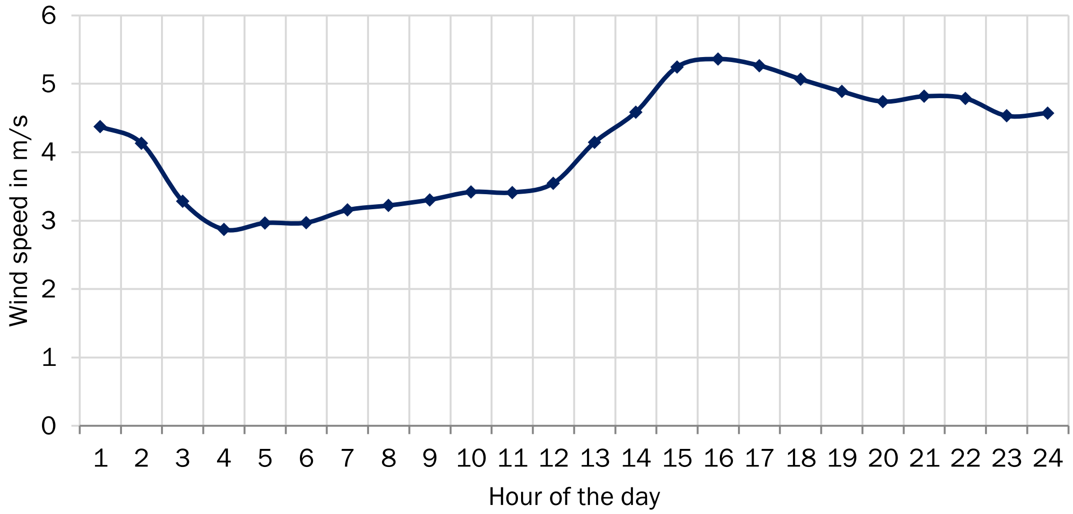

Figure 9: Daily wind speed profile during off-season (January 2018).

Using the wind speed data for January 2018 and the power characteristics of the selected WEC, Table 6 illustrates daily average energy generation for off-season. The nighttime energy yield is slightly higher than the daytime yield.

Table 6: Daily energy yield in January 2018 at Feni during off season (January).

Hour of day	Mean wind speed (m/s)	Power (kW)	Period	Energy yield (kWh)
1	4.38	4.5536	Night	4.5536
2	4.13	3.6236	Night	3.6236
3	3.28	1.4859	Night	1.4859
4	2.87	0.7474	Night	0.7474
5	2.97	0.9494	Night	0.9494
6	2.97	0.9494	Night	0.9494
7	3.16	1.282	Day	1.282
8	3.22	1.384	Day	1.384
9	3.30	1.5199	Day	1.5199
10	3.42	1.724	Day	1.724
11	3.41	1.707	Day	1.707
12	3.55	1.9879	Day	1.9879
13	4.15	3.698	Day	3.698
14	4.59	5.5939	Day	5.5939
15	5.25	10.395	Day	10.395
16	5.36	11.3168	Day	11.3168

17	5.27	10.5625	Day	10.5625
18	5.07	8.8866	Night	8.8866
19	4.89	7.5739	Night	7.5739
20	4.74	6.584	Night	6.584
21	4.82	7.112	Night	7.112
22	4.79	6.914	Night	6.914
23	4.53	5.198	Night	5.198
24	4.57	5.462	Night	5.462
			Energy yield during day (kWh)	**51.17**
			Energy yield during night (kWh)	**60.04**
			Total daily energy yield (kWh)	**111.21**

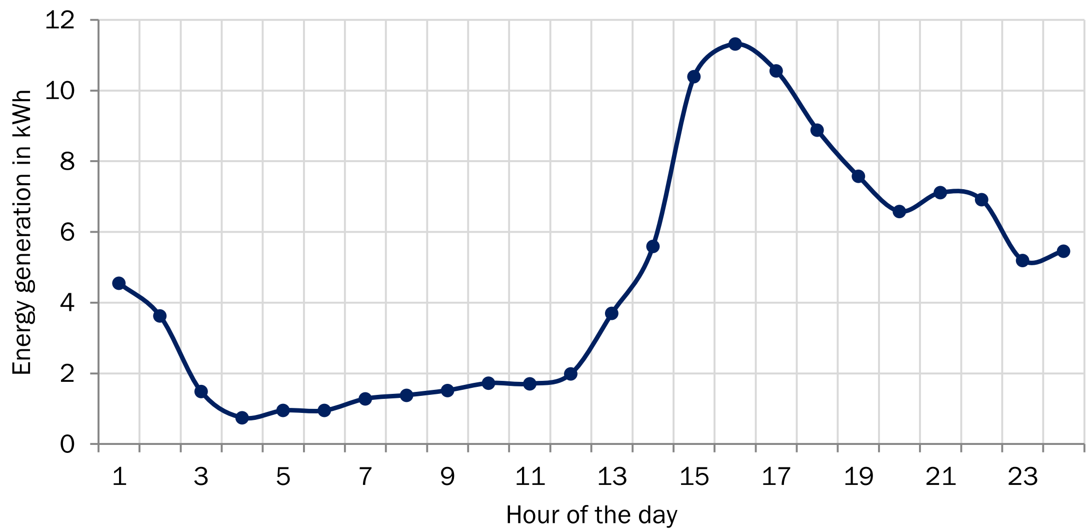

Figure 10: Hourly wind energy generation during off season (January 2018).

3.5 Daily energy yield during peak season (July, 2018)

Summer and monsoon months along the coastal area of Bangladesh are characterized by higher wind speeds. The monthly variation of wind speed at Feni in Figure 3 illustrates that the highest average wind speed is recorded in the month of July. Figure 11 shows daily average wind speed profile for the month of July 2018. The diurnal variation in wind speed during the peak season is not as prominent as it is observed during the off-peak season.

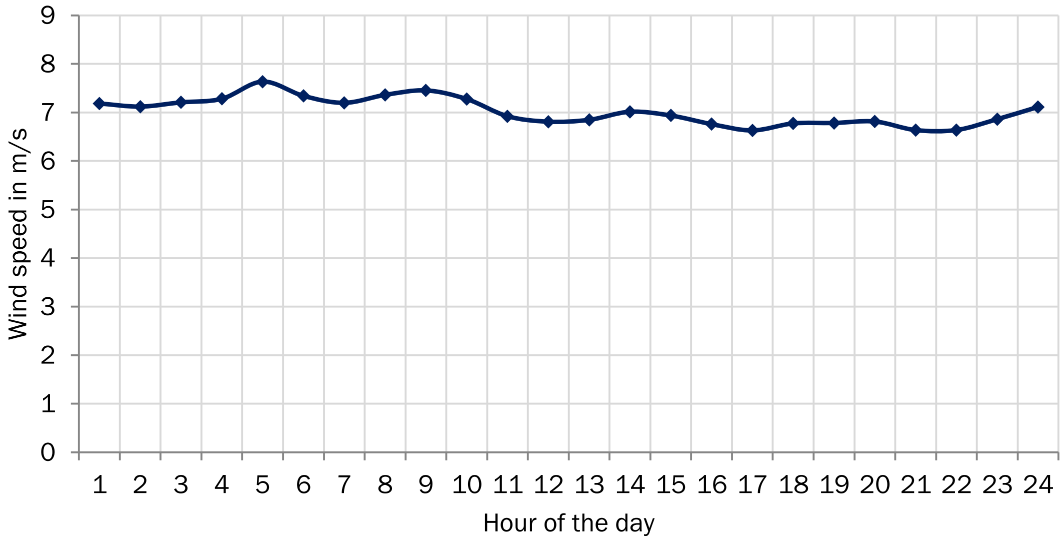

Figure 11: Daily wind speed profile during peak season (July 2018).

Table 7 shows the energy generation calculation for a typical day in July 2018.

Table 7: Daily energy yield calculation in July 2018 at Feni.

Hour of day	Mean wind speed (m/s)	Power (kW)	Period	Energy yield (kWh)
1	7.18	38.4075	Night	38.4075
2	7.12	37.1584	Night	37.1584
3	7.21	39.0322	Night	39.0322
4	7.28	40.4896	Night	40.4896
5	7.64	48.5952	Night	48.5952
6	7.34	41.7388	Day	41.7388
7	7.20	38.824	Day	38.824
8	7.36	42.1552	Day	42.1552
9	7.45	44.029	Day	44.029
10	7.28	40.4896	Day	40.4896
11	6.92	33.1752	Day	33.1752
12	6.81	31.1336	Day	31.1336
13	6.85	31.8759	Day	31.8759
14	7.01	34.8682	Day	34.8682
15	6.94	33.5464	Day	33.5464
16	6.76	30.2056	Day	30.2056
17	6.63	27.7928	Day	27.7928

18	6.77	30.3912	Day	30.3912
19	6.78	30.5768	Night	30.5768
20	6.81	31.1336	Night	31.1336
21	6.64	27.9784	Night	27.9784
22	6.64	27.9784	Night	27.9784
23	6.86	32.0616	Night	32.0616
24	7.11	36.9502	Night	36.9502
			Energy yield during day (kWh)	**460.23**
			Energy yield during night (kWh)	**390.36**
			Total daily energy yield (kWh)	**850.59**

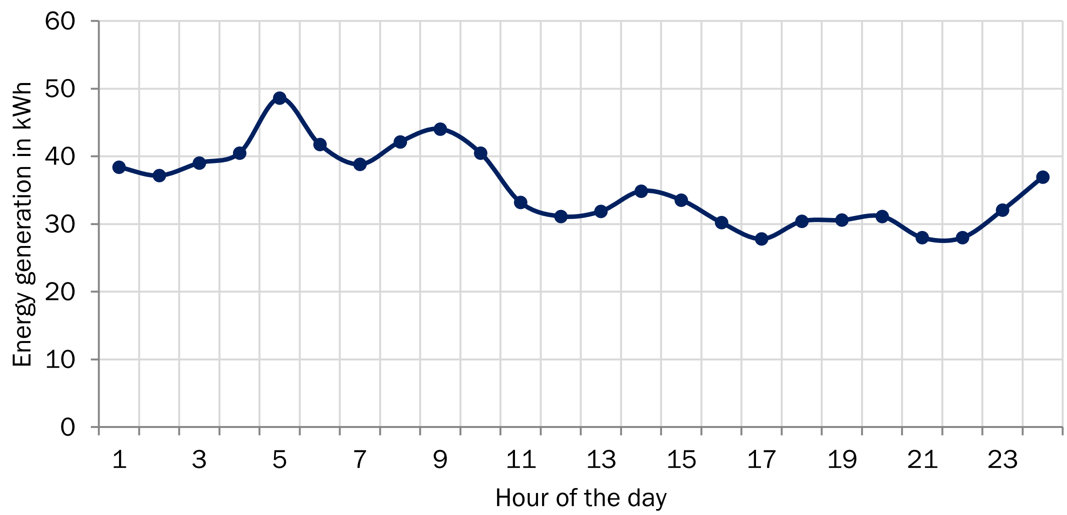

Figure 12: Hourly wind energy generation during peak season (July 2018).

The daily energy yield calculation presented in Table 6 and Table 7 reveals that integrating a WEC into the solar mini-grid will be especially beneficial during the winter season, when sunshine duration is less. On the other hand, the WEC will act as a complementary energy source to solar mini-grid by producing energy at nighttime. Nevertheless, it should be kept in mind that this analysis is based on the wind data available at a location in Feni. The diurnal characteristics of wind speed might be different at Monpura.

3.6 Uncertainties in energy yield calculation at Feni

The uncertainties in the energy yield calculation originate from multiple sources. The major issues are discussed below:

- The use of secondary wind speed data may contribute to errors in the calculation.
- Data interpolation from the selected wind turbine's power output may also contribute to errors in the calculation.
- Of note is that the daily yield has been calculated based on hourly average data for the month of January. Wind speed is usually low during the winter season. Therefore, corresponding power output is also very low resulting in overall low energy generation. During other seasons, generation will be much higher corresponding to the higher wind speed values available during those months.

3.7 Annual energy yield at Monpura

The detailed calculation presented in this report, especially that of the energy yield is based on the data for the district of Feni, instead of Monpura, Bhola because of the availability of high-resolution data needed for the analysis. However, low-resolution wind speed data reveal that average wind speed at Monpura is higher than that of Feni. Figure 13 illustrates the difference in average wind speed distribution between these two sites, from which it can be concluded that Monpura on average has higher wind speed areas.

Even though average wind speed at a certain area is not a conclusive indicator of annual energy yield, it can still provide some idea regarding the power extraction potential. Figure 14 shows the power density between these two sites, which suggests that the power density is greater at Monpura than Feni. Therefore, it can be safely concluded that the energy yield from the wind turbine integrated at Monpura will be greater over a year. Data for this comparison has been collected from the GWA 2.0.

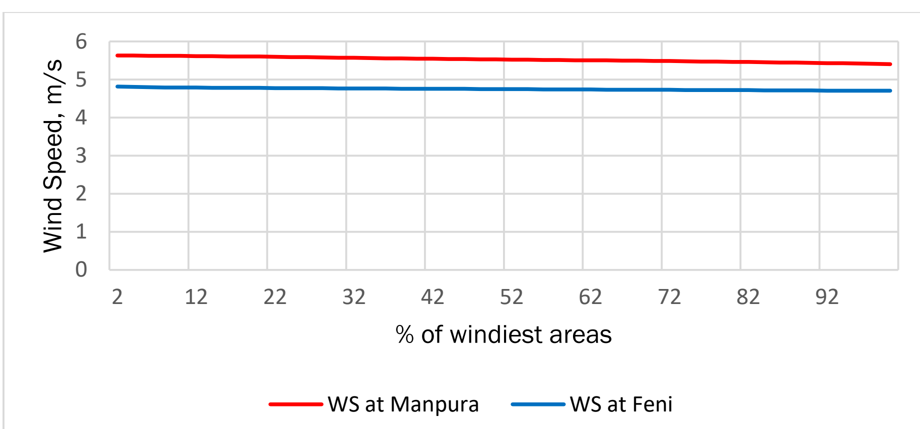

Figure 13: Comparison of average wind speed distribution at Monpura and Feni.

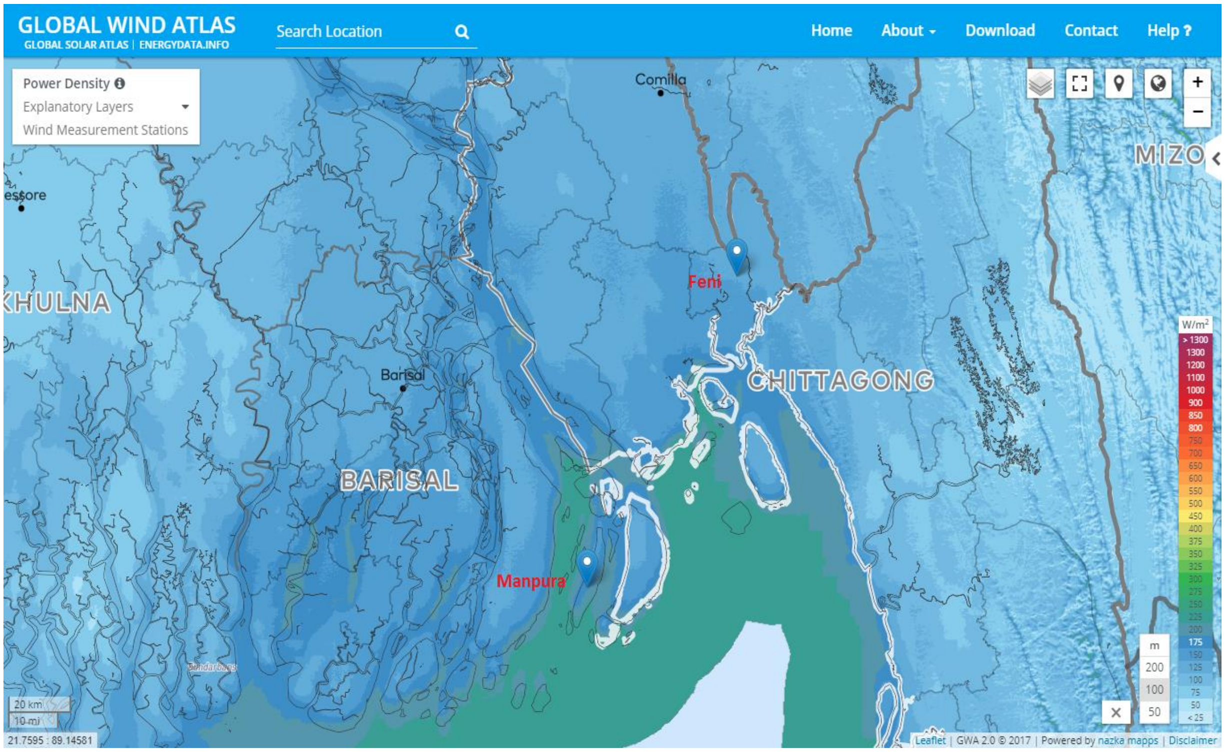

Figure 14: Wind power potential map of Feni and Monpura at 100 m hub height.

Source: [18].

4 Key informant (KI) interviews

Different stakeholders involved into the project were consulted (Key Informant) on the implementation of wind energy converter at Monpura Island. The interviews and discussions were held between 5 and 18 September, 2018. The summary of discussion and interviews are tabulated below while the details of option analyses based on the KII are given in Section 7.

Name	Persons met	Discussion outcome
Sustainable and Renewable Energy Development Authority (SREDA)	1. **Md. Helal Uddin** Chairman, SREDA 2. **Mr. Siddique Zobair** Member, EE&C, SREDA 3. **Ms. Salima Jahan** Member, RE, SREDA	SREDA opined for an wind energy converter (WEC) on a pilot basis integrated into a solar PV-diesel hybrid mini-grid at Monpura Island. As monitored wind speed data at the project location is not available, the main objective of SREDA is to integrate the WEC with solar mini-grid and to investigate the yield and whether the technology combination can reduce the need for storage. If UNDP does not provide additional grant support (e.g. 60%-40% model) because of the existing private ownership, and rather opts for IDCOL financing model (50% grant and the rest from equity and loan) of solar mini-grid projects, then SREDA is willing to take the ownership of the project. In this case, SREDA will engage the mini-grid sponsor as an operator for the operation and maintenance under a lease agreement based on certain conditions. The storage and transmission line of the solar -mini grid would be used and wind will be integrated to the hybrid system. SREDA acknowledged that the UNDP might be able to finance 100% of the cost under SREDA ownership. SREDA also pointed out that the wind turbine could also be used for wind resource assessment under the USAID project, which did not include any coastal location in their assessment.
IDCOL	1. **Mr. Enamul K Pavel** Head of RE 2. **Ms. Farzana Rahman** Unit Head, Other RE	IDCOL opined that as the WT will be included into the SMG project, there should be provision of adding more customers. IDCOL suggested that the exact wind potential is not known a priori. Therefore, UNDP should

	3. **Mr. Hasan M. Tushar** Asst. Manager, RE	ideally consider 60 % grant support to accommodate for the risk factor. Moreover, the procurement process should be the same as other IDCOL-supported SMG projects.
Western Renewable Energy Limited (WREL)	1. **Mr. Fahim Alam** Advisor 2. **Mr. Qaiyum Bappy** Project Manager	WREL management is not keen on investing on a technology which is not yet proven in Bangladesh and would like UNDP to provide 90% grant support of the cost of integrating wind energy systems in their SMG project.
UNDP	1. **Mr. Khurshid Alam** Asst. Country Director 2. **Arif Md. Faisal** Program Specialist, Resilience and Incremental growth Cluster 3. **Taibur Rahman** SREPGen Project Manager	UNDP opined that they are unable go beyond the existing grant distribution mechanism of 50% grant and 50% from equity and loan, without strong justification. They can provide 100% grant support only to a government agency or a not–for–profit organization such as NGO, but not to a profit–making private sector company. UNDP also expressed that a technical feasibility based on available secondary information would be a pre-requisite for considering financing as infeasible investments must be avoided. Business model and subsequent procurement processes are the main concern of UNDP. With a strong support from the Government, UNDP may consider this project as a pilot. However, the project must be owned by the Government through, for example, SREDA. Appropriate technical specifications considering the characteristics of the proposed location and estimated costs are the other two important aspects UNDP wanted to have further clarity on from this report.

5 Specification of suitable wind turbine

This section focuses on the specification of the wind turbine for integrating into the solar mini-grid at Monpura, Bhola. Typical WEC within this capacity range have at least 20 years of design life. It is also common practice for WEC manufacturers to provide a 5–year warranty, which includes no-cost maintenance services. After careful analysis of the WEC specifications from various manufactures, recommended parameters for 100 kW WEC and the generator have been ascertained and presented in Table 8.

Table 8: Recommended specifications of a 100 kW WEC.

No.	Parameter	Unit	Value/feature
	Wind Turbine		
1	Minimum Capacity	kW	100
2	Maximum power generation capacity	kW	120
3	Cut-in/start-up wind speed	m/s	2.5
4	Rated wind speed	m/s	10
5	Survival wind speed	m/s	>55
6	Design life time	years	20
7	Rotor diameter	m	>24
8	Swept area	m^2	>450
9	Rated rotor speed	rpm	55
10	Blade material	-	Fiber glass
11	Tower type	-	Monopole tower
12	Tower height (Hub)	m	60
13	Warranty	year	5
	Generator		
1	Drive type		Direct (without gear box)
2	Generator type	-	Three phase permanent magnet synchronous generator
3	Control system	-	Electronic
4	Rated Voltage	V	> 400
5	Working temperature	°C	-40 to 80
6	Speed regulation	-	Active yaw control
7	Brake	-	Spindle hydraulic
8	Warranty	year	5

The rated wind speed of 10 m/s indicates that the WEC will generate energy at its rated capacity (~100 kW) at that wind speed. Typically, WEC operation is stopped when wind speed reaches 30 m/s for safety reasons. But it is even safer to install a WEC that can withstand excessive thrust load caused by higher wind speed. This aspect is especially important for this integration project mainly because of the location. The coastal belt of Bangladesh is hit by irregular wind speed spikes during the monsoon months, as well as cyclones and adverse wind conditions.

Mechanical gears under loads undergo severe wear and erosion. As a result, generators with gear boxes demand higher maintenance effort. Therefore, a generator without a gear box is likely to reduce maintenance cost during the operational life of the WEC.

Apart from the technical specifications provided in Table 8, the WEC must have safety and protection systems, such as mechanical pitch control, mechanical rotor secure lock, dump load box, grid failure and power loss protection.

6 Cost of 100 kW wind turbine integration

This Section presents a preliminary estimation of cost of integrating a 100 kW wind turbine system with a 280 kWp solar diesel hybrid mini-grid at South Sakuchia of Monpura Island, Bhola. The solar mini-grid (SMG) under consideration is owned by Western Renewable Energy Limited (WREL). Therefore, the project will benefit from major cost reductions in capital expenditure related to the civil and electrical system construction because of the existing solar mini-grid infrastructure.

The present study considers the installation of a wind turbine with its own storage along the coastal belt and will be connected to the SMG through a double circuit 0.4 kV transmission/distribution line. The additional generated energy will be distributed to both the existing and new customers. Distribution capacity, therefore, needs to be increased, for which a new 2 km distribution line has been added to the system configuration. All costs are estimated through a desk-based analysis where reference prices were taken from the market, as well as from the similar recently–approved IDCOL projects. 2% contingency has been added to the estimated project cost.

Table 9 illustrates the cost breakdown and the total estimated cost of the integration of 100 kW wind turbine at Monpura, Bhola.

Table 9: Estimated Cost break down of 100 kW WT integration project.

No.	Item Description	Unit	Qty.	Unit price BDT	Item cost BDT	Item cost USD[1]
1	Land	Bigha	2	470,250.00	940,500.00	11,196.43
2	Civil Construction *Only the control room building and WT footing are land-filled. Boundary is fenced with barbed wire.*	lot	1	3,400,000.00	3,400,000.00	40,476.19
3	100 kW wind turbine at 60 m hub height[2]	lot	1		31,000,000.00	369,047.62
4	Off grid inverter SI8.0H: Master	pcs	1	379,960.00	379,960.00	4,523.33
5	Off grid inverter SI8.0H: Slave	pcs	2	363,887.00	727,774.00	8,663.98
6	Battery 1540 Ah	pcs	48	41,000.00	1,968,000.00	23,428.57
7	Multi-cluster and junction box	item	1	500,000.00	500,000.00	5,952.38
8	Circuit Breaker: 160 A MCCB and safety equipment	item	1	50,000.00	50,000.00	595.24
9	Interconnection cables and installation	lot	1	1,000,000.00	1,000,000.00	11,904.76
10	Power evacuation line to connect WT with SMG: 0.4 kV double circuit	km	2	1,700,000.00	3,400,000.00	40,476.19
11	Single-phase distribution line	km	4	1,100,000.00	4,400,000.00	52,380.95
12	Online energy meter	pcs	1	250,000.00	250,000.00	2,976.19
13	Single-phase energy meter	pcs	100	4,220.00	622,000.00	7,404.76
14	Service connection wire: BYA 2*2 RM	m	2000	40	80,000.00	952.38
15	EIA consultancy and legal agreement				315,000.00	3,750.00
16	Remote monitoring system				600,000.00	7,142.86
17	Transportation of equipment excluding WT				500,000.00	5,952.38
Sub Total					50,133,234.00	596,824.21
Contingency of 2%					1,002,664.68	11,936.48
Grand total					51,135,898.68	608,760.70

Notes:

1. 1 USD = 84 BDT
2. The cost component 3 in the table includes the following items:

- Price of the 100 kW turbine, including all its components, including grid on pitch control system, grid on inverter;
- Cost of 60 m high tower;
- Port clearance and taxes;
- Turbine transportation cost;
- Cost of civil construction of the foundation;
- Cost of additional electrical works;
- Cost of erection and commissioning; and
- Cost of operation and maintenance for 5 years.

7 Financing options and justifications

This section discusses available options and justifications of various financing options for integrating a wind energy converter (WEC) with the existing solar mini-grid on a pilot basis. The options are developed based on the interviews with the key stakeholders, as detailed in Section 5.

7.1 Option A: Build-own-operate

Option A1: for the solar-wind hybrid mini-grid power system based on the build-own-operate (BOO) model and financed by 50% grant and 50% from loan and equity.

There are seventeen operational solar mini-grids in Bangladesh facilitated by IDCOL and financed by the World Bank, kfW and other development partners. These solar mini-grids followed the same business model where a private sponsor submits a proposal to IDCOL for loan (30% of total cost) and grant (50% of total cost) financing. Solar mini-grids are owned and managed by different actors for covering the upfront and the on-going operation and maintenance cost of the system. IDCOL has a guideline to assess and subsequently accept/reject the unsolicited proposals that can be submitted at any time. IDCOL evaluates the proposal based on the set criteria and financial analysis, and if the proposal passes these assessments, IDCOL board approves the financing decision. IDCOL approaches a development partner for grant financing at 50% of the total cost. It should be noted that all costs are subject to IDCOL's assessment and market verification. Once approved, the sponsors procure the goods and services under close monitoring of IDCOL.

For the solar-wind hybrid project to be installed at Monpura, a sponsor has been assessed. This hybrid system is unique with some uncertainties related to energy generation and their impact on business and sustainable operation of the mini-grid. After rigorous analysis and discussions, the sponsor has expressed its unwillingness to experiment with this proposed unique system following the existing 50-50 financing mechanism; i.e., 50% grant and 50% from loan and equity. IDCOL, SREDA and the sponsor have been consulted and further financial analysis has been carried out by both IDCOL and this consultancy.

Option A2: for the solar-wind hybrid mini-grid power system is based on the build-own-operate (BOO) model and financed by 60% grant and 40% from loan and equity.

Based on the analysis and extensive discussions, it has been agreed that 60% grant financing instead of current practice of 50% for solar mini-grid would be a fair and justified mechanism considering the risks and uncertainties associated with wind energy generation, its operation and maintenance and most importantly its integration with the solar system. The remaining 40% would be a combination of loan and equity of the total cost, in proportion to the existing financial structure.

Thus, this solar-wind hybrid system would be a unique project in Bangladesh with an innovative business model. Operational model under this option is feasible for the sponsor who will be responsible for construction and operation of the project under strict supervision of IDCOL, SREDA and UNDP. All procurements will also be accomplished by the sponsor in this model. Supplier of the wind-turbine will provide at least five years of O&M service in any case thus guaranteeing the smooth operation of the turbine at the beginning. However, concerns with land purchase and land development would be (actually have been) ameliorated by the sponsor who will also undertake all civil works necessary for the wind turbine. UNDP's agreement on this model will ensure a speedy implementation of the project with quick procurement. The availability of online metered data will enable close monitoring of system and business performance by the stakeholders.

Only concern in Option A2 (the new business model of 60%-40%), as opposed to Option A1 of 50%-50% (grant to loan + equity share) is that it needs to be agreed on by UNDP. It should be noted that SREDA, IDCOL and the sponsor has agreed on this business model.

7.2 Option B: Build-lease-operate

Option B for the solar-wind hybrid mini-grid power system is based on the build-lease-operate (BLO) model and financed by 100% grant for the wind part and 50% grant for the solar part.

Under this option the total cost of 100 kW capacity Wind Turbine Generator (WTG) and its associated cost for integration will be derived from UNDP as grant support (100% grant) and ownership will be retained by the Government (SREDA in this case). Details of this option are as follows.

- Solar mini-grid part of the project will be procured, constructed and managed following the established 50%-50% (grant and loan + equity) business model.
- SREDA or UNDP will arrange the bidding process to select the supplier of the wind turbine at earliest along with technical support for the integration with the solar-mini-grid.
- The sponsor of the solar mini-grid part will be responsible for required land purchase, land development, civil works for the wind part along with the procurement of the inverter, required transmission line and battery storage for integration. The sponsor will be reimbursed either by the winning bidder for the supply of the wind turbine or by the SREPGen through IDCOL.

- SREDA will take the full ownership of this wind part pilot project.
- SREDA will have an agreement or will lease this out to the solar-mini-grid sponsor later on when electricity generation from wind turbine becomes stable with some degree of certainty.
- Under that agreement or lease, the sponsor will operate, ensure proper and effective maintenance and electricity generation.
- The sponsor will be responsible for selling generated electricity to the consumer at an agreed tariff and share profits, if any, with SREDA. A separate agreement will be signed between SREDA and the sponsor for the sharing of the profits from the wind part of the project.

The justifications for the details of the arrangement are as follows.

- SREDA will help the sponsor for the purchasing of land and other relevant support from the local government.
- After successful erection, a close monitoring of the wind turbine generator will take place for a period of three to four months or until it becomes a stable system.
- An agreement between SREDA and the sponsor will be signed after achieving system stability.
- The bilateral agreement will clearly specify the O&M schedule and scheme, as well as the mechanism for profit sharing between SREDA and the sponsor.
- Both SREDA and SREPGen are keen to assess the wind potential at Monpura island. This pilot project will help to provide wind data at project site. SREPGen would provide the financial support under “Wind Resource Assessment” (Component-2) if further support is required against the wind turbine generator pilot project.

The potential challenges are as follows.

- There is a lack of reliable wind speed data for the site. The estimation of the potential electricity generation is, therefore, uncertain.
- The proposed project will be the largest onshore wind project (in terms of single WT) around the coastal belt of Bangladesh. Reliable information on operational performance and business performance are not available to make informed decisions at the planning stage.
- The location is prone to adverse wind conditions such as cyclone. Because of the lack of precedents, it is difficult to ascertain the potential risks resulting from adverse weather.

- Ownership and operational agreement with sponsor are also challenging.

However, this is an acceptable mechanism in terms of ownership by the government against 100% financing from UNDP/GEF.

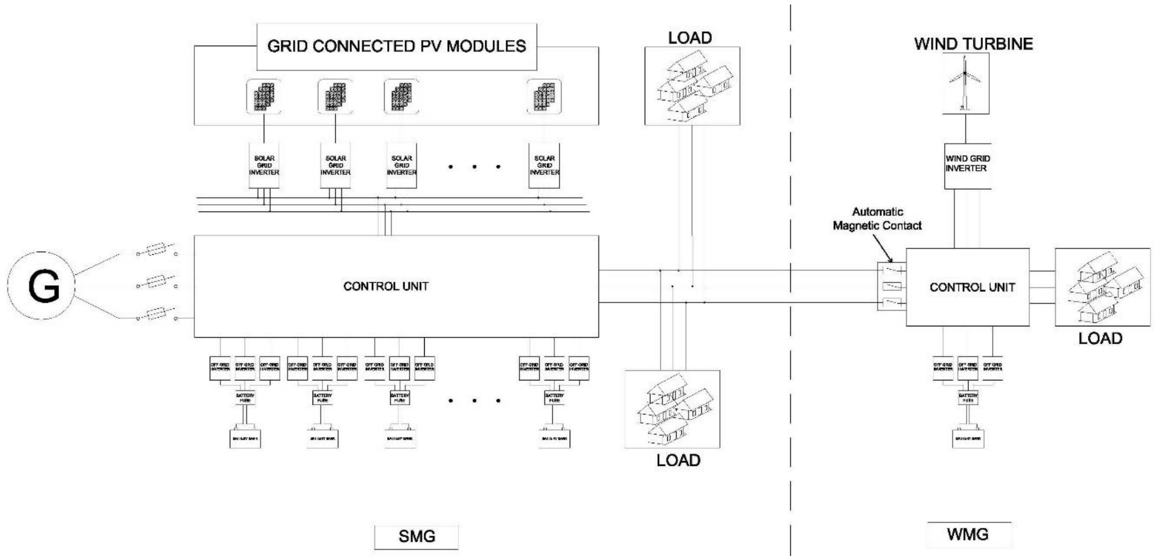

Figure 15: Schematic diagram of off-grid wind converter integrated into solar mini-grid.

7.3 Option C: Financing two solar mini-grids

Option C illustrates the implementation of two solar mini-grids at Monpura with innovative operational models financed via the existing mechanism comprising a loan of 30%, equity of 20% and a grant of 50% of the total cost.

Two solar mini-grids have already been approved by the IDCOL board. 279.5 kW capacity solar mini-grid at South Sakuchia has been proposed to be financed from SREPGen project (50% grant) with potential to be integrated with a wind system. Another mini-grid of 218 kW capacity at the northern part of Monpura has been proposed to be financed by KfW. Considering the annual work plan of SREPGen and its budget availability these two solar mini-grids can be financed from the SREPGen project with some innovative operational system such as the introduction of peak and off-peak tariffs. Ideally, both mini-grids should implement the same tariff from a consumer point of view as different tariffs in a small geographical area of an upazila may not be acceptable. On this ground, IDCOL can be approached by SREDA/SREPGen for financing both mini-grids.

SREPGen will still have some budget left for wind assessment at coastal areas. A wind energy system can be introduced next year with the remaining budget under an open tendering process as it would take some time.

8 Recommended procurement method

This section of the report aims to propose a procurement method for wind turbine integration project at Monpura, Bhola.

At present, IDCOL follows a standard procurement method for solar PV-diesel hybrid mini-grid projects. In this process, IDCOL collects at least three quotations from the equipment suppliers. IDCOL then analyses the specifications, quality claims and the price of the equipment under consideration. This analysis sometimes involves stakeholder (individual consultant, project developer and development partners) consultations. Sponsor then procures equipment from the recommended suppliers at the quoted price.

The procurement method to be followed for the 100 kW wind turbine integration project at Monpura, Bhola can be similar to this standard procedure in case of **Option A1 and A2** mentioned in Section 7. Solar mini-grid would also follow this procurement system in case of **Option C**.

In case of **Option B**, SREDA or UNDP has to procure the wind turbine system following an open tendering process. The sponsor of the solar mini-grid part will be responsible for the required land purchase, land development, civil works for wind part along with the procurement of the inverter, required transmission line and battery storage for integration and will be reimbursed either by the winning bidder for wind turbine supply or by the SREPGen through IDCOL. If deemed justified, these can also be included in the procurement package of wind turbine. However, it will be challenging for an international firm to purchase land at Monpura. Practical issues such as this need to be considered while packaging items.

9 Operation and maintenance plan

Since the 100 kW wind turbine (WT) will be integrated with the existing solar mini-grid, the WT operation and maintenance (O&M) schedule should also be integrated with that of the existing O&M plan of the solar PV-diesel mini-grid. This section of the report will only focus on the O&M plan of the integrated wind turbine for brevity.

Typical O&M responsibilities associated with wind turbine projects include the following [23]:

- Overseeing operations, repair and maintenance of the balance of plant (BOP) including but not limited to substation, collector system, interconnection transmission lines, roads, grounds, foundations, transformers, etc.
- Performing all maintenance and repair related activities that are sufficient to maintain the BOP in good working condition, consistent with sensible business practices and applicable O&M manuals.
- Maintaining all materials, including spare parts inventory, required to maintain the BOP in the normal course of business.
- Preparing purchase orders to procure parts, materials and supplies necessary for the operation, maintenance and repair.
- Scheduling power outages and maintenance shutdowns in coordination with the turbine schedule provider(s), power purchaser(s) and transmission provider(s) to minimize revenue loss and interference with facility operations.
- Supervising, monitoring and reporting on the operations and maintenance of interconnection facilities, in accordance with the interconnection agreement.
- Responding to trips as reported by the auto-dial monitoring system and providing trip reports of all faults, defects and breakdowns occurring in respect of such electrical systems.
- Calibrating power and energy meters.
- Producing monthly operating reports including turbine performance, BOP performance, safety and environmental matters, and others.
- Coordinating and pursuing all warranty and insurance related claims against suppliers of materials and equipment to the BOP or Turbines.
- Operating and maintaining the WT in compliance with all governmental requirements, Loan and Material Project Documents.
- Producing and providing facility data and information requested by any concerned authority.

- Provide SCADA overlay service which includes tracking, trending, and internet access to the dashboard as well as the record of the facility data.

9.1 Operation Plan

The main objective of the operation plan for wind turbine is to optimize the generation capacity and maximize the availability, while ensuring safety and smooth operation.

9.1.1 Team and shift plan

The O&M team of the wind turbine system should comprise at least five personnel. One site supervisor/operator should be assisted by two technicians and two security staff. The line man or the distribution system should be taken care of by the technical persons from the SMG. It is to be noted that, unlike solar PV generators, the wind turbine also produces electricity at night, the duty shifts should be devised accordingly.

9.1.2 Operation logbook

An operational logbook should be kept and well maintained. The following items are usually recorded in the operational logbook:

- Facility mode or condition changes
- Abnormal facility configurations
- Status changes to safety related and other major facility equipment
- Occurrence of any reportable event
- Security incidents
- Shift relief
- Maintenance actions
- Site or equipment problems and corrective actions
- Other significant evolutions involving the associated system/equipment or shift positions

A template for operation logbook is provided in **Appendix B**.

9.2 Maintenance Plan

Like any other power producing equipment, wind turbines also require regular maintenance to ensure maximum energy yield over its service life. Apart from the turbine itself, the collection systems, etc. should undergo inspection and maintenance on a regular basis as well for proper and undisturbed operation.

9.2.1 Maintenance activities

A detailed plan and schedule should be prepared for maintenance activities. Ideal maintenance activities of wind turbine should serve three general objectives, as follows.

- Corrective maintenance, when any damage/malfunction has already occurred;
- Preventive maintenance, to prevent potential damages in future and to ensure smooth and reliable operation of the WT;
- Improvement maintenance, to increase the plant efficiency and maximize energy yield.

9.2.2 Maintenance schedule & checklist

The corresponding schedule should come along with a checklist. Keeping photographic records of turbine condition is also an advisable practice for proper maintenance of WTs. Typically, the maintenance checklist is used for four different maintenance schedules, as follows.

- 500 hour;
- Half year;
- 1 year; and
- 3 years.

Furthermore, checklists should be prepared with the maintenance schedule of the wind turbine. Depending on the type and manufacturer, the individual components of the checklist may change. It is also a common practice for manufacturers to provide an initial maintenance plan within the warranty and servicing period. However, the maintenance plan for the following years should be prepared in consultation with the manufacturers, if possible. A typical maintenance schedule and a checklist is provided in Appendix C.

9.2.3 Maintenance logbook

It is also a common practice to maintain a maintenance logbook with the turbine. The logbook should record the following items:

- Details of failure;
- Repair activities;
- Modifications;
- New adjustments; and
- Any other point of concern regarding the maintenance.

The operators should have easy access to the maintenance manual at all times.

10 Key technical risks and mitigation measures

According to the REN21 report on global renewable energy status, challenges of integrating variable renewable energy (VRE) systems are often overstated. It states that *low shares of VRE can be managed with modest adjustments, such as improved resource forecasting, improved grid codes (interconnection standards), better real-time information flow on VRE output, and sensible planning of geographical dispersion and balancing of wind and solar power installations (which often have complementary generation profiles).* [8]

The case under consideration is an off-grid system and is connected to a storage system, so the VRE system will not hamper the operation of the system that much. The main risk can come to handle the excess power by using dummy loads. This section of the report investigates general risks associated with 100 kW wind turbine integration project at Monpura, Bhola. The risks may arise from all three phases of a wind turbine's life cycle, which are planning, construction and operation. Table 10 lists the identified risks that may arise during the lifecycle of a wind turbine.

Table 10: List of major risks of wind turbine integration project.

Project phase	Technical risk	Recommended mitigation measure
Planning	**Geographic location** of the proposed plant is close to the cyclone-prone coastal area. According to Bangladesh National Building Code (BNBC) the basic wind speed at that area is 80 m/s. There is hardly any wind turbine manufacturer in the world who produces wind turbine that can withstand such wind speed.	The wind turbine should have proper insurance against cyclones and storms. Civil construction design should address the high wind speed issues.
	Geological condition of the project location can impart considerable risks, which should be addressed during the planning phase. Adverse soil condition may not only affect the construction of the wind turbine, but also its lifetime.	Proper site surveys and relevant soil testing should be conducted in the planning phase of the project.
	Grid connection (in this case with the existing mini-grid) specifics can be another source of potential risks. Constructing new transmission line	During the planning phase, the exact location of the wind turbine installation should be decided to

	can be expensive and impact the project finance.	minimize the need for new transmission line construction.
Construction	Transportation of the expensive and delicate components and the lifting crane poses some serious risks. The access roads should be able to transport the heavy loads.	The associated risks can be mitigated by hiring specialist transportation providers with prior experience.
	Ability of the cranes to lift the turbine components up to the desired height is another source of risk.	
	Casual storage of equipment before the actual erection process can cause damage as well.	The equipment should be properly stored, and the erection process should be planned to minimize inventory time.
	Deviation from the standard interconnection procedure may result in major operational hazards of the entire mini-grid.	Existing interconnection standards must be followed during the integration process.
Operation	Variable power input from the wind turbine can put the mini-grid stability under threat.	This risk can be mitigated by adopting steps such as resource forecasting, and by ensuring dissipation of excess power by dummy loads.
	Gearbox damage is one of the most significant technical risks of WTs. Since mechanical load is placed on the gearbox, extreme friction can cause erosion of the teeth of the planet gear.	The project should use direct-drive wind turbines; i.e. gearbox less.
	Rotor damage is one of the most expensive losses for wind projects. Both the rotor hub and blades should be regularly inspected for potential malfunctions and defects that may have originated during the manufacturing process.	A camera solution can be used for blade inspection services, which can make use of computer vision techniques to identify wear and tear, allowing asset owners to rectify issues at an early stage.
	Lightning strikes can be one of the most frequent external causes of WT damage, depending on the geographical location of the project. They also affect the internal connections, causing shutdown of the turbine.	Proper installation of lightning rod (both on monitoring systems and blades) and regular blade inspections can prevent potentially substantial losses from lightning strikes.
	Fire damage is not uncommon for wind projects. The main risk of fire hazard lies in its propensity to	Installation of fire detection, protection and suppression systems is a must to prevent damage by fire hazards.

	spread. However, the reason of fire can be numerous.	
	Failures of electrical equipment is another major source of technical risk. Specially, converters are highly prone to failure. Technical problems of the converter correspond to nearly 30% of the regular failures.	The converter should be compartmentalized from the rest of the system and regular maintenance should be conducted. Keeping sufficient reserve of spare parts greatly reduces downtime due to electrical failures.

11 Recommendation and conclusion

The main objective of the work is to investigate the feasibility of developing a pilot mini-grid project that integrates a wind energy converter with a solar mini-grid system. The IDCOL-financed solar mini-grid at south Sakuchia of Monpura Island, Bhola district has been selected for piloting. As primary hourly wind speed data for the site was not available, secondary wind speed data for the nearest location at Feni district has been utilized for energy yield calculation. Analysis suggests that electricity generated from wind is highest in July. Annual energy yield at Feni from a 100 kW wind turbine at 60 meter hub height is 183.5 MWh, whereas daily average generation is 509 kWh. However, the monthly average wind speed data for Monpura was available, which was found to be 15-17% greater than Feni. If Monpura's higher monthly average wind speed is taken into consideration, the estimated generation at Monpura can be considered 17% higher than Feni. Hence, the estimated annual energy yield at Monpura is approximately 214.7 MWh, assuming that the wind speeds between the sites are linearly related. Daily average yields in January and July at Monpura are 111.2 kWh and 850.6 kWh respectively.

The concept developed for the wind integration is such that, the wind energy converter along with its storage system will be installed close to coastal belt and will be connected to the solar mini-grid through a double circuit 0.4 kW transmission/distribution line. The additional energy generated from wind will be distributed to additional consumers. A 2 km distribution line has been added to the calculations for the newly acquired additional consumers. Costs were estimated through a desk-based analysis, in which reference prices were taken from the market, as well as from the similar projects recently approved by IDCOL. 2% contingency has been allocated in the project cost.

Key stakeholders of the pilot wind energy system, UNDP, SREDA, IDCOL and WREL were interviewed to identify a suitable financing and operating model. Four options for financing and operation and maintenance have been identified from the discussions.

The first option (A1) follows the existing financing structure of IDCOL for solar mini-grid projects. But the sponsor did not agree to this arrangement, primarily because of the risks associated with implementing a relatively new technology at this scale in Bangladesh, precedents for which do not exist in the country.

The second option (A2) is to provide 10% more grant support for the project than the norm, at 60% of the project cost. But even though IDCOL and the sponsor have agreed in favor of this option, it is not acceptable by UNDP as they do not want go beyond the norm.

The third option resulted from the discussions between UNDP and SREDA. UNDP suggested that they can provide 100% grant support for the pilot project, if it is owned by the Government or a not-for-profit organization. In this option, the system will be owned by SREDA but will lease to WREL for operation and maintenance. As the project is projected to make profits; therefore, any profit arising from the operation will be shared between SREDA and the operating partners. A memorandum of understanding (MoU) for profit sharing can be agreed in the absence of a concrete projection of operating profits.

The fourth option gives the UNDP the opportunity to discard the idea of financing this wind integration pilot and allocate the grant to another suitable SMG project with an innovative idea, either during design or operation.

The literature and this assessment support the assertion that wind energy conversion is feasible in coastal belts in Bangladesh. It is, therefore, essential to support innovative and early-adopter projects aimed at integrating wind energy with the existing infrastructure — to accelerate the pace of technology adoption. The proposed wind-solar hybrid mini-grid can be an exemplar for other similar projects. Given the importance of pilot implementation in convincing the business and the consumer of the viability of a technology, this report suggests that one of the first three financing options can be chosen by the UNDP.

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13 Appendices

Appendix A: Template for operational logbook

The following chart is a recommended template for 100 kW wind turbine to be integrated at Monpura, Bhola (adopted from [24]):

Date: ____/ ____/ ______	
Operator:	
Log Sheet No.	Log Sheet Title:
Time	**Activity**

Appendix B: Maintenance Schedule & Checklist

A typical maintenance plan and corresponding checklist is presented below [25, 26]:

General Information

Details of wind turbine

Project Name/ Location :
Serial number :

Ambient condition

Wind Speed :
Temperature (outdoor) :

Maintenance activity details

Responsible for maintenance work :
Date of last maintenance :
Interval of the last maintenance :
Date of this maintenance :

500 hr	1/2 year	1 year	3 years	Items to be inspected and maintained	Checked by	Remarks
Tower						
G	G	G	G	Foundation		
G B	G B	G T B	G T B	Flanges and welding		
G	G	G	G	Ladder and platform (if any)		
G	G	G	G	Safety equipment		
G B	G B	G B	G B	Tower yaw bearing		
G B	G B	G B	G B	Yaw bearing nacelle		
G	G	G	G	Visual		
Nacelle						
G B	G B	G T	G T	Mainframe		
G B	G B	G O	G O	Gearbox mounts to main frame connection		

G B	G B	G T	G T	End plate to gear box mounting		
G	G	G	G	Rubber Buffer		
G C	G C	G C	G C	Silica gel breathre		
G	G	G	G	Tooth system		
G	G	G	G	Mechanical pump		
G O	G O	G O	G O	Oil sample		
G	G	G	G	Oil level		
G	G	G	G	Visual inspection of housing		
G	G	G	G	Hoses		
Rotor						
B	B	T B	T B	Pitch system		
G	G	G	G	Blades		
G L	G L	G L	G L	Pitch bearing		
G	G	G	G C	Flap Shaft bearing		
G	G	G L	G L	Synchronization bearing		
G		G	G	Blade-angle adjustment		
G		G	G	Rotor brake adjustment		
G	G	G	G	Pitch string		
G	G	C	C	Rubber 'O' rings chain rotor blade		
B	B	B	B	Bolt connection		
G		G	G	Buffers		
G	G	G	G	Visual		
Yaw System						
G L	G L	G L	G L	Yaw bearing		
G B	G	G T B	G T B	Yaw system		
G B	G	G T B	G T B	Yaw brake		
G	G	G T B	G T B	Cable twist sensor		
G	G	G T B	G T B	Anemometer		
G	G	G	G	Visual		
Electrical Installation						
G B	G B	G	G	Bolt connection		

G	G	G	G	Cables/wiring		
G	G	G	G	Contact from main current contractors		
G	G	G	G	Capacitors		
G	G B	G C	G C	Ventilation/air filters		
	G			Function test		
G	G	G	G	Visual		

Notes:
G = General inspection; B = Bolts tightening; C = Change; L = Lubricating; T = Test;

14 Biography of Consultant

Education & Employment

Shahriar Ahmed Chowdhury obtained his B.Sc. in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology (BUET) in 1997 and M.Sc. in Renewable Energy from University of Oldenburg, Germany in 2006 with the highest marks in the graduating class. He has the working experience in Bangladesh power sector for a decade. He worked in system control & grid circle (DESA) and planning & design (BPDB). Currently he is working as the Director of Centre for Energy Research at United International University (UIU). He has designed and initiated a course in Renewable Energy for the first time in Bangladesh for the undergraduate students of EEE department in 2007.

Research Acheivements and Awards

Shahriar has invented a novel dry fabrication process (alternate buffer layer) for CIGS thin film solar cell with highest efficiency at the time (2006) in Centre for Solar Energy and Hydrogen Research at Stuttgart, Germany. In 2016 one of his research project “Peer-to-Peer Smart Village Grid” funded by IDCOL / WB won the “UN Momentum for Change” award in UNFCCC CoP 22 in Marrakesh, Morroco and “Intersolar Award” in Munich, Germany. His Research projects “Smart Solar Irrigation System” and “Demand Response Enabled Smart Grid” won the “Inter University Innovation Award” at Power and Energy Week 2016 & 2018 respectively, organized by the Ministry of Power, Energy and Mineral Resources. Mr. Chowdhury was the supervisor of the finalist student project for the IEEE International Future Energy Challenge, 2009 in Illinois Institute of Technology, Chicago, USA. In June, 2018 he received the “Education Leadership Award” from “World Education Congress, 2018“ in Mumbai, India for his contribution in Education, Research, Leadership and Teaching in the Renewable Energy sector.

Works and Affiliations

As a team leader he has performed the first two technical auditing of the SHSs installed all over Bangladesh under IDCOL program. He is extensively involved in developments of grid connected and off-grid solar PV systems. He is the designer of the first ever utility-scale grid connected solar PV project of Bangladesh (Engreen Sharishabari 3.28 MWp, came into operation in August, 2017). He is involved in designing Kaptai 7.4 MW (BPDB) and Sirajganj 7.6 MWp (NWPGCL) solar PV projects. He is also supporting RPCL for the development of their 250 MWp grid tied solar PV project at Mollahat, Bagerhat. So far he has designed more than 25 solar diesel hybrid minigrids for rural electrification (Out of 17 operational solar minidgrids for rural electrification under IDCOL financing, he has designed 16). He has also designed several rooftop solar PV systems ranging from 25 kWp to 3 MWp. He has drafted the Net Metering Policy Guideline for Bangladesh. The Guideline has been approved in July, 2018 by the Ministry of Power, Energy and Mineral Resources of Bangladesh.

As a power & energy sector expert he was involved in projects like Bangladesh Delta Plan 2100, Bangladesh Energy and Emission Modeling 2050, Supporting implementation of Bangladesh Climate Change Strategy and Action Plan (BCCSAP), Bangladesh off grid energy sector assessment, etc. He has working experience in projects funded by GoB, IDCOL, World Bank, UNDP, ADB, DFID, EPSRC, DECC, GIZ, kfW, JICA etc. He has developed a solar PV minigrid laboratory at his University by the grant support from IDCOL and the World Bank. Mr. Chowdhury has jointly initiated a bi-yearly International Conference on Renewable Energy (ICDRET), this is first conference of its’ kind in Bangladesh [So far successfully organized 5 events]. He is the author of more than 45 book articles, journal papers and conference proceedings. He has working and project experience in Bangladesh, Germany, UK, Kenya and Nigeria. He is the Member of Expert Panel of International Electro-technical Commission (IEC) for Systems Evaluation Group (SEG 4) on "Low Voltage Direct Current Applications”.