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Feasibility Study Report

Feasibility Study for Development of Utility Scale Solar PV & Wind Projects in Bangladesh

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Feasibility Study Report for Development of Utility Scale Solar PV & Wind Projects in Bangladesh

Client

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DISCLAIMER

This study has been carried out in good faith in order to provide a comprehensive documentation of the expert evaluation and analysis of the project at its current status, based on the information available at the time of the study. However, the consultant makes no warranty – implied or expressive – with respect to the accuracy, correctness, completeness or appropriateness of any information contained in this document. The information in this document is solely for the use of the client and may only be used for the agreed purpose. The Consultant undertakes no duty to or accepts no responsibility to any third party who may rely on this document.

PREFACE AND ACKNOWLEDGEMENT

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PowerCell, Ministry of Power, Energy and Mineral Resources, Government of Bangladesh (GoB) has planned to enhance its renewable energy capacity and to gear up to meet the demand for growth of the sector and the economy of the Country.

The Director General of PowerCell signed a contract on 04th December 2016 to appoint M/s WFMS Management Services Pvt Ltd, India (WFMS) as consultant for conducting "*Feasibility Study for Development of Utility Scale Solar PV & Wind Projects in Bangladesh*" at identified location (Contract package No. S-89).

WFMS, M/s Suntrace GmbH – Germany (Suntrace) and M/s EQMS Consulting Ltd – Bangladesh (EQMS) are in consortium for delivering this assignment.

This assignment is to provide consultancy services to develop a comprehensive feasibility study as per terms of reference (TOR) to take further decisions by PowerCell and World Bank (financer of this assignment).

WFMS has submitted the inception report (task 1 of TOR) and first version of draft feasibility study report (FSR) (task 2 of TOR) of the assignment.

The main objective of this assignment is to prepare FSR for viable solar PV and wind energy power project at the project site.

We would like to thank Mr. Mohd Hossain - Director General-PowerCell, Mr. Md. Abdur Rouf Miah – Director (Sustainable Energy), Mr Q.A. Sharhan Sadique – Deputy Director (Sustainable Energy) and Dr. Kazi M Humayun Kabir – Project Director for Electricity Generation Company of Bangladesh (EGCB) for their unstinted support, guidance and patience. Without their leadership and vision, this project would not have been conceptualised and planned.

We are also thankful to Mr. Zubair Sadique – Senior Energy Specialist of World Bank and Mr. Joonkyung Seong of World Bank for their drive, zeal and long term commitment to the development of sustainable energy in Bangladesh.

Last but not the least we would like to thank all the staff members of the Sonagazi Upazilla UNO office, PGCB and EGCB for their cooperation and hospitality to WFMS and consortium members.

We apologise for not being able to individually name each and every person who have contributed, guided and enriched this report.

EXECUTIVE SUMMARY

The Government of Bangladesh (GOB) has taken a systematic approach towards renewable energy (RE) development including relevant policy and institutional development. As per the National Renewable Energy Policy 2008, the plan is to add 2000 MW by 2020 from renewable sources. EGCBL has identified a potential site to develop an aggregate capacity of 200 MW from solar PV and wind at Sonagazi Upazilla under Feni District. In continuation to this RE deployment in the country, "Power Cell", Power Division, Ministry of Power, Energy, & Mineral Resources (the Client) is carrying out a project "Feasibility Study for Development of Utility-Scale Solar PV and Wind Project Bangladesh" financed and supported by World Bank under the ongoing Rural Electrification and Renewable Energy Development II (RERED II). This project will meet the national renewable energy plan of Bangladesh as outlined in the National Renewable Energy Policy 2008 and will also serve a potential path to avail the RE benefits towards sustainable development of the country.

The Client has appointed WinDForce Management Services Pvt. Ltd. (WFMS) - India in consortium with Suntrace GmbH - Germany and EQMS Consulting Ltd. – Bangladesh through international competitive bidding and tendering process to prepare a feasibility study report. The aim of the project is to support the development of utility-scale solar PV and wind power at Sonagazi Upazilla under Feni District in Bangladesh to address the national renewable energy plan of Bangladesh.

This feasibility study report outlines the techno-economic feasibility of setting up Solar PV and Wind Power project at Sonagazi Upazilla under Feni District of Bangladesh.

This feasibility study has identified and assessed all possible options of capacity mix at the site to meet different objectives of technology mix, costs of generation, sustainability etc. set by Power Cell and EGCB. Following are the identified and assessed options:

1.) Option 1 (reference case): it has 100 MWac (136.06 MWdc) solar PV with 24 MWac wind.

2.) Option 2: it has the reference case (100 MWac solar PV with 24 MWac wind) plus additional 54MWac solar PV in between shadow free area of WTGs.

3.) Option 3: it has only solar PV of 262 MWac (356.53 MWdc) at the entire site and no wind power system.

4.) Option 4: it has 172 MWac (234.050 MWdc) solar PV and 10 MWac wind power project with 262 acres (26% of entire land) for livelihood purpose like fishery and agriculture around WTGs area.

5.) Option 5: It has 166 MWac (225.85 MWdc) solar PV and 10 MWac wind power project with Fishery activity beneath the solar PV modules.

6.) Option 6: It has 182 MWac (247 MWdc) solar PV power project with Fishery activity beneath the solar PV modules.

7.) Option 7 (recommended option): It has 200 MWac (272 MWdc) solar PV power project with intensive fishery on around 25% land of the total area for livelihood purpose (no wind power project).

The following options were analyzed so far, created.

Option 1 (Reference Case)	Solar PV with Wind in distinct manner
Option 2	Solar PV with Wind in distinct manner along with extra Solar PV in WTGs shadow free area
Option 3	Only Solar PV with no wind
Option 4	Solar PV with Wind and Fishery activity in distinct manner
Option 5	Solar PV with Fishery activity beneath the Solar panels and Wind
Option 6	Only Solar PV with fishery activity beneath the solar panels with no Wind
Option 7 (Recommended option)	Only Solar PV with Fishery activity in distinct manner without wind

For solar PV technology selection and comparative study we have used Option 1 (reference case) solar PV (100 MWac) as reference.

Technical description of suitable solar PV technology

During the conceptual layout optimisation and technology selection, the reference case based on 100 MWac has been considered. The resulting plant parameters of the reference case have been applied for assessing different capacity options and evaluate the recommended option for the project site.

The study has analysed different technical options including module technology and mounting structure and conceptual plant parameters such as the optimal tilt angle, pitch, and DC/AC ratio of the system have been optimised. The following table shows the variation of module technologies for the reference case scenario:

Parameter	Unit	p-Si	m-Si	Thin film
Energy Yield	GWh/a	202.02	204.57	206.84
Total area	Ha	135	135	130
DC Power	MWp	136	138	136
Module cost	USD/kWp	320	357	350
CAPEX	M USD	144.76	151.08	148.58
OPEX	M USD	1.73	1.76	1.73
LCOE	USD cents/kWh	9.36	9.60	9.34

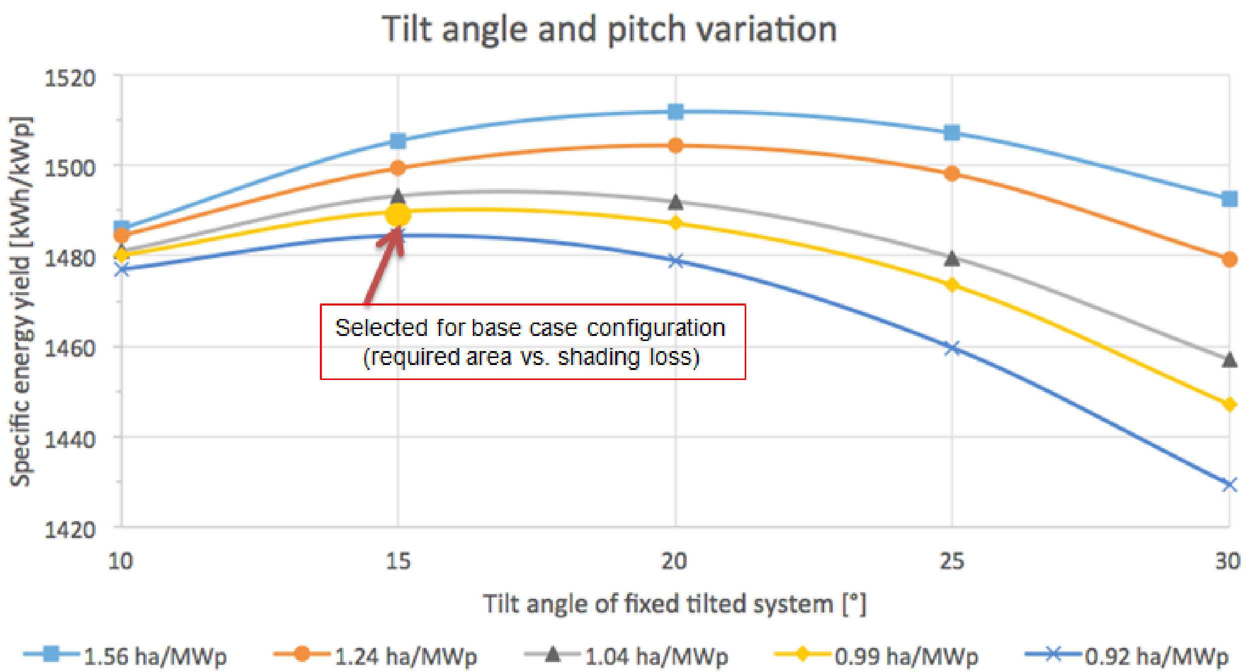
The analysis has shown that the polycrystalline module technology offers not only a considerable track record and proven reliability, but also a slight cost advantage in term of LCOEs compared to monocrystalline modules and similar results when compared to thin film technology, and has thus been selected for further analysis. The thin film and monocrystalline module technologies however should not be excluded during tendering stage.

Moreover, the single axis tracked system has been examined more closely. The following table shows the analysis of different mounting systems for the 100 MW_{AC} reference case solar PV power plant:

Parameter	Unit	Fixed-tilt system	Single axis tracking system
Energy Yield	GWh/year	202.02	222.88
Total area	Ha	135	227
CAPEX	M USD	144.76	154.82
OPEX	M USD	1.73	1.98
LCOE	USD cents/kWh	9.36	9.13

Single axis tracking system has less cost in terms of LCOE compared to fixed-tilt system and the specific yield is about 10% higher while about 68% more area per MWac is required. Due to short field experience with trackers and complications posed by flooding at the site, fixed-tilt system is considered for this study. As Single axis tracking system are showing increasing adoption in recent years, selection of mounting system can be left open to bidders during tendering stage.

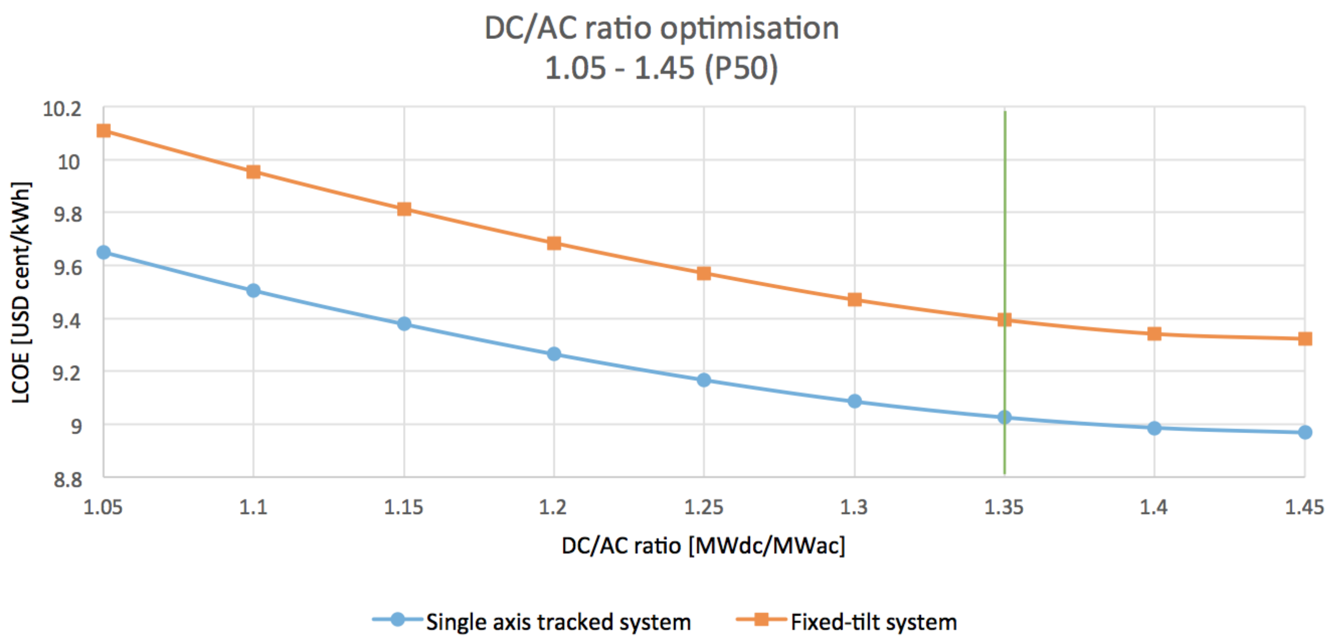
Subsequently, the tilt angle and pitch (distance between rows) has been optimised for the selected fixed-tilt system. The following figure shows the results of the tilt angle and pitch variation.



Source: *Simulation*

The above figure shows that a low specific area requirement of 1ha/MWp has been selected for the fixed-tilt system resulting in an optimal tilt angle of 15° and a pitch of 8.9m (GCR 65%) with shading loss <2% compared to the case with 1.56 ha/MWp.

Moreover,the DC module capacity has been optimised against the AC inverter output capacity in terms of a techno-economic optimisation, as shown in the below figure. A DC/AC ratio larger or equal than 1.35 provides most attractive LCOEs for both, the fixed-tilt system and the single axis tracked system, with only marginal differences if further increased to 1.4 or 1.45. For technical reasons a DC/AC ratio of 1.36 has been considered for the reference case.



Source: *Simulation*

To analyse suitable capacities, the economies of scale have been estimated in the following. The table shows the analysis of different system capacities for the fixed-tilt reference case configuration:

Parameter	Unit	260MWac	100 MWac	50 MWac	30 MWac	10 MWac
Energy Yield	GWh/a	525.25	202.02	101.01	60.61	20.20
Total area	Ha	351	135	67	40	14
CAPEX	M USD	308.26	144.76	80.42	60.16	35.05

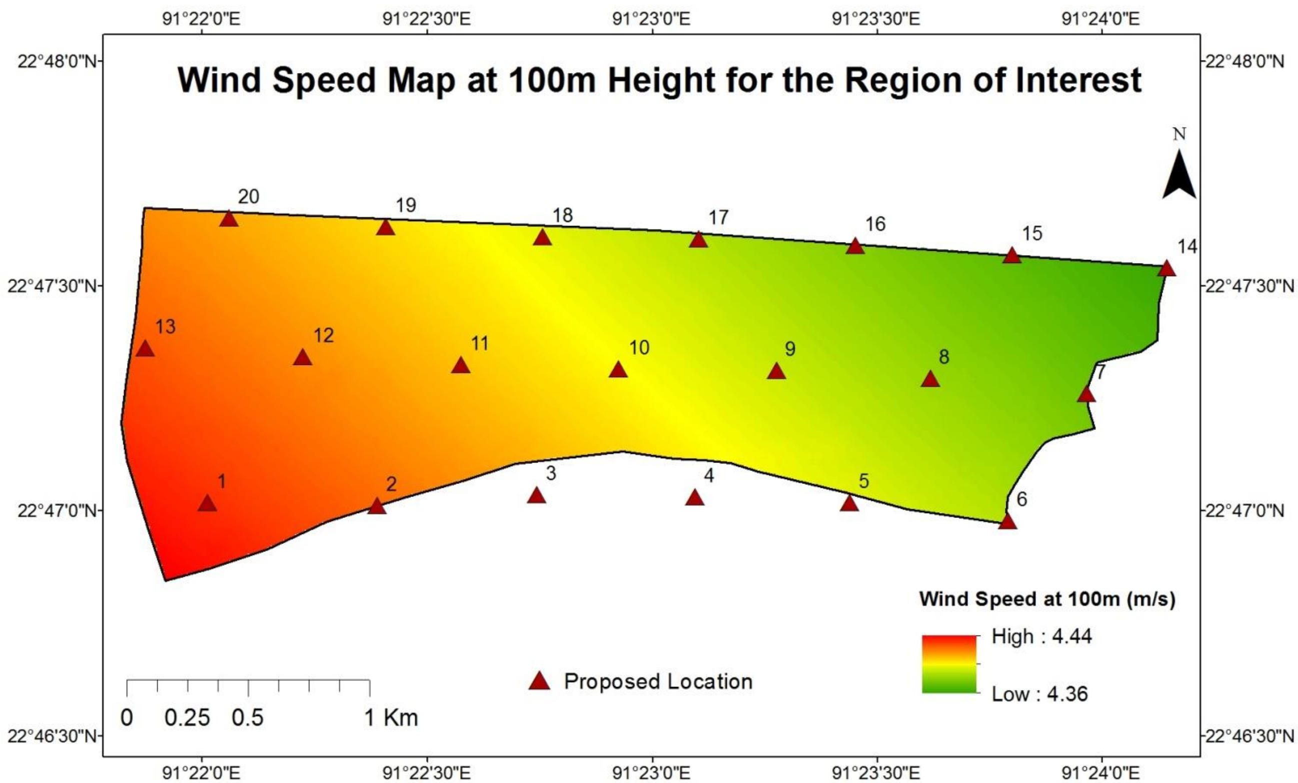
OPEX	M USD	4.23	1.73	0.95	0.63	0.23
LCOE	USD cents/kWh	7.70	9.36	10.58	13.20	23.14

The above table shows that, with decreasing system capacities, the LCOE increases due to the economies of scale. A large capacity >30 MW for the pilot project is recommended also to get international players into bidding.

In general, it should be noted that the evaluation of different technical configurations during the feasibility analysis is based on the applied technical and financial assumptions. During tendering stage, the layout optimisation and selection of modules, inverters, mounting structure, DC/AC ratio etc. should be left open to the bidders. The tender documents should provide the minimum technical specifications and information required to enable competitive and responsive bids and not a bill of material.

Technical description of suitable wind technology

This study shows the average wind speed for the Region of Interest (RoI) at a typical hub-height of 100 m above the ground (observing the long term wind speed trends), as shown in the below map (with best 20 wind turbine locations across the entire site):



Source: *Simulation*

Selected wind turbine generators (WTG) are known for operating in low wind regions with the capability of generating power at a lower cut-in wind speeds. These wind turbine generators which have wider blades, can reach rated power at wind speeds much lower than compared to other WTG models.

These WTG models are mainstream IEC-61400 fully certified turbine. The typical technological parameters about the WTG models have been tabulated below:

Technical Specification	Gamesa G114	Vestas V110	Suzlon S111	Unit
Rated Power	2	2	2.1	MW
Wind Class	IIIA	IIIA	IIIA	-
Rotor diameter	114	110	111	m
Hub Height	106	110	120	m
Swept Area	10,207	9,503	9,817	m^2
Generator type	Doubly Fed Generator	Doubly Fed Generator with slip rings	DFIG-Asynchronous with slip rings operated with rotor circuit inverter system	-
Cut-in wind speed	3	3	3	m/sec
Cut-out wind speed	20	25	21	m/sec

In this task, the potential capacity of the site was assessed considering the trade-off between performance of wind turbines and land utilization per megawatt of capacity installed. The three best in class wind generators: Gamesa-G114-2.0MW, Vestas-V110-2.0 MW and Suzlon-S111-2.1MW models have been considered while estimating the long term energy yields as it represents predominant wind technology and appropriate WTG class suited at the site. These WTG models are mainstream IEC-61400 fully certified turbine. Micrositing was carried out with both the above models with turbine spacing criteria i.e. 5D x 7D to arrive at an optimal layout of the wind-farm. The model optimized the positioning of WTGs considering the gross energy yield, spacing criteria and existing terrain.

PLF values at probabilities of exceedance (PoE) P50 and P75 and gross & net AEP using Gamesa G114 2.0 MW, Vestas V110 2.0 MW and Suzlon S111 2.1 MW WTG models with spacing criteria of 5D x 7D have been derived at the wind farm level consisting all identified 20 WTG locations at the site is given in below table.

WTGs Model	PoE	*Gross AEP (GWh/year)	*Gross PLF (%)	**Net AEP (GWh/year)	**Net PLF (%)
Gamesa G114-2MW	P50	66.46	18.97%	57.93	16.53%
Gamesa G114-2MW	P75	52.91	15.10%	46.12	13.16%
Vestas G110-2MW	P50	62.73	17.90%	54.68	15.60%
Vestas G110-2MW	P75	49.18	14.03%	42.87	12.23%

Selected technology:

The study has analysed and identified following suitable technology for the project:

1.) A fixed-tilt solar PV system based on central inverter and polycrystalline module technology stands out as the preferred configuration for the project site.

2.) Gamesa G114 2.0MW Model stands out as the preferred configuration for the site.

Capacity mix options

The following options were analyzed so far, created to meet different objectives of technology mix, costs of generation, sustainability etc. set by Power Cell and EGCB.

Option 1 (Reference Case)	100 MWac (136.06 MWdc) Solar PV with 24 MWac Wind in distinct manner
Option 2	100 MWac (136.06 MWdc) Solar PV with 24 MWac Wind in distinct manner along with extra 54MWac Solar PV in WTGs shadow free area.
Option 3	Only 262 MWac (356.53 MWdc) Solar PV with no wind
Option 4	172 MWac (234.050 MWdc) Solar PV with 10 MWac Wind and Intensive fishery activity

	on 262 acres (26% of entire land) , in distinct manner.
Option 5	166 MWac (225.85 MWdc) Solar PV with Semi Intensive fishery activity beneath the Solar panels and 10 MWac Wind.
Option 6	Only 182 MWac (247 MWdc) Solar PV with semi intensive fishery activity beneath the solar panels with no Wind.
Option7 (recommended case)	200MW AC (272 MWdc) Solar PV and Intensive fishery activity on balance land (no wind)

Different objectives of technology mix, costs of generation, sustainability etc. set by Power Cell and EGCB, Option 7 comes out the more suitable option among all.

Rationale for the recommended option 7:

a.) Following comparative analysis shows the rationale to choose the Option 7 as the recommended option (Only Solar PV, No wind):

Solar PV	Wind
Site is having good solar resource and generation potential. (As per resource potential assessment)	Site is having less wind resource and generation potential.
1 MWdc solar PV would require 2.4 Acres land (1 MWac solar PV would require 3.3 Acres land)	1 MWac wind would require 7.4 Acres land
If 10 MWac wind (74.3 Acres of land) is replaced with complete solar PV then it can accommodate additional ≈30 MWdc solar PV capacity on the same land.	
30 MWac solar PV would produce 58 GWhr per year net electricity	10 MWac wind (using same land as 30 Mwac Solar) would produce 14.9 GWhr per year net electricity
LCOE = 10 USD cents / kWh (As per financial analysis, it does not include the cost and revenue of fishery, but it includes fishery's impacts on foundation, civil & Structure cost).	LCOE = 18 USD cents / kWh

Associated Infrastructure cost: for solar PV need to strengthen the existing 4 m wide road it costs around 23.77 Mn Taka, there is no need of development of a new road or Jetty.	Associated Infrastructure cost: for wind along with solar PV need to develop 9.8 m wide new road (this stretch of road consists of 3 Bridges of 8m, 20m, 30m respectively and 2 Culverts (both of 3m length), it costs around 147.1 Mn Taka. there would be need of detailed study and development of a new road or Jetty.

For the proposed site only solar PV installation with no wind is recommended, based on comparative analysis.

b.) Following comparative analysis shows the rationale to choose the Option 7 as the recommended option (Only Solar PV with Intensive Fishery at open land in distinct manner):

Parameters	Intensive Fish Culture	Semi Intensive Fish Culture
Production (kg per year per Acre)	40000 @40 MT/acre	4000 @4 MT/acre
OPEX (Taka per year per Acre)	3200000 @80 BDT/kg	240000 @60 BDT/kg
Revenue (Taka per year per Acre)	5600000 @140 BDT/kg	560000 @140 BDT/kg
Capex (Taka per Acre)	600000 (@15BDT/kg	80000 @20 BDT/kg
Operation of Solar Plant	Fish culture independent – solar production can be maximized. No O&M Difficulties	Solar panels will be spaced at a larger pitch. O&M difficulties in accessing panels through a Boat
LCOE of solar plant accommodating fishery specification	10.1 USD cents/kWh	10.8 USD cents/kWh

Intensive fish culture on open land is a better option to Semi-intensive fish culture beneath the panels, due to 10 times better productivity (fish productivity), relatively higher solar generation (in term of units generated), lower LCOE, and less operational complexity.

Conclusion: Based on GoB Bangladesh's requirement of livelihood, site parameters/location, ease in EPC & O&M, financial attractiveness and comparative study, Option 7 comes out as more appropriate option for the proposed site. Hence Option 7 is the recommended option from this feasibility assessment study. The recommended Option 7 would be developed in two phases

Project development

This study has presented two phases of development of this project, in Phase-1 solar PV of 50 MWac capacity will be executed and remaining solar PV i.e. 150 MWac solar PV capacity will be executed in Phase-2. Following table shows the proposed phasing for the recommended Option 7:

Parameter	Unit	Phase-1	Phase-2	Remark
		Solar PV	Balance Solar PV	
Capacity	MWdc	68	204	Land leveling, associated dike & infrastructure work, Pooling SS and Approach Road will be developed.
	MWac	50	150	
	Total MWac	200		
Model	-	EPC, with 5 years O&M	BOOT model	Phase-2: Tariff discovered through bidding.
Ownership	-	EGCB	IPP/PPP	
Power sale	-	BPDB	BPDB	
Expected date of commissioning	-	Apr-19	Apr-20	

Financial analysis

The project financials have been analysed using a tailor-made financial model. During the techno-financial analysis target equity IRR of 15% has been applied to determine the respective LCOE for each PV plant configuration. The key input parameters for the financial model are, among others, the technical input data, such as the estimated annual electricity yield, the investment cost (CAPEX), operation and maintenance cost (OPEX) and assumptions regarding the financing scheme. Along with these parameters, data and standard formulas are used to perform the calculations.

The study identified the potential installation capacity of solar PV and wind along with its LCOE (financial analysis) for all the prepared Options, which as follows:

Parameter	Unit	Option 1		Option 2		Option 3		Option 4		Option 5		Option 6		Option 7	
		Solar PV	Wind	Solar PV	Wind	Solar PV	Wind	Solar PV	Wind	Solar PV	Wind	Solar PV	Wind	Solar PV	Wind
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology.													
		Wind: Gamesa G114 2.0MW Model													
Capacity	MWdc	136	24	210	24	357	-	234	10	226	10	248	0	272	0
	MWac	100	24	154	24	262	-	172	10	166	10	182	10	200	
	Total MWac	124		178		262		182		176		192		200	
Net Energy Yield	GWhr/yr	196.36	30.69	301.24	30.69	514.51	0.00	337.74	12.79	327.26	12.79	360.15	0.00	392.44	0.00
Total Area	Ha	134.57	26.45	207.24	26.45	352.57		231.45	11.02	291.16	11.02	319.22	0.00	269.13	0.00
CAPEX	m USD	129.91	36.23	184.41	34.80	292.42	0.00	208.42	14.44	222.30	14.69	241.79	0.00	237.00	0.00
OPEX	m USD/annum	1.71	0.48	2.55	0.48	4.21	0.00	2.99	0.20	3.67	0.20	4.01	0.00	3.42	0.00
LCOE	USD cents / kWh	11.32	19.53	10.28	18.56	9.43	0.00	10.30	17.82	11.49	18.07	11.33	0.00	10.04	0.00
Wt. Avg. LCOE USD Cent/kWh		12.53		11.11		9.43		10.61		11.76		11.33		10.04	

The weighted average of phase 1 and phase 2 Levelized Cost of Energy (LCOE) for the recommended option 7 configuration with 200 MW_{AC} is 10.04 USD cents / kWh with an annual electricity production of 392.7 GWh/yr (net) at P75 confidence level.

The study identified the potential installation capacity of solar PV with its LCOE (financial analysis) for recommended option 7, which is as follows (P75):

Option 7 (in two Phases)			
Parameter	Unit	Phase-1	Phase-2
		Solar PV	Solar PV
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	
Capacity	MWdc	68	204
	MWac	50	150
	Total MWac	200	
Net Energy Yield	GWhr/yr	98.12	294.32
Total Area	Ha	67.3	201.85
CAPEX	m USD	66.37	170.63
OPEX	m USD	0.94	2.48
LCOE	USD cents / kWh	10.18	9.99

As we know, solar PV technology is cheaper than power generation by diesel/HFO generators, unit cost of electricity generation is 25.80 to 38.40 Tk/kWh average HSD generation cost and 14.15 to 19.30 Tk/kWh HFO generation cost (BPDB, annual report 2015-2016). Cost of power generation by renewable energy is fixed for its project lifetime e.g. 25 years for solar PV, whereas cost of power generation by diesel generators is subject to inflation.

Economic analysis

Considering externalities and benefits economic analysis has been done, following table shows the economic analysis result of this assessed seven options:

Following table shows the economic analysis of the all assessed Options:

Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
ERR- Diesel replacement	%	28.70%	32.59%	38.51%	34.15%	32.18%	33.34%	35.78%
NPV- Diesel replacement	MnUSD	307.24	478.96	791.57	588.06	494.96	530.05	659.39
Payback period- Diesel replacement	#years	3.59	3.16	2.66	2.99	3.18	3.07	2.85
ERR- HFO replacement	%	22.00%	25.01%	29.54%	27.26%	24.86%	25.74%	28.45%
NPV- HFO replacement	MnUSD	191.33	309.92	530.9	410.1	322.32	347.59	460.43
Payback period- HFO replacement	#years	4.69	4.12	3.48	3.75	4.12	3.98	3.59

As can be seen from the above financial and economic analysis that, among proposed seven Options, Option 3 seems more economically viable compare to other options, but as per the requirement of the country, site and client to cater livelihood along with this project, Option 7 seems suitable among all (as rationale to choose Option 7 has been provided in above section).

Hence in this FSR we have considered Option 7 more suitable to the site. However decision is open with the client to choose any Option as per their further requirements.

Following table shows the economic analysis (3E evaluation) of Option 7 (recommended option):

Economic Analysis (3E evaluation) of the recommended final option 7					
3E	**Parameter**	**Unit**	**Diesel Replacement**	**HFO Replacement**	**Remark**
Economic	ERR	%	36%	28%	
	NPV	m USD	659.39	460.43	
	Payback period	Years	2.85	3.59	
	SC-CO2	m USD	88.20	100.73	This assumes social carbon value of avoided CO2 emissions as per USEPA, considered for entire project life @ 14 USD/tCO2, 5% average, 2020-2030.
Environment	GHG	ktCO2e	6299.738	7194.872	Carbon emission savings over the life of the project

	emissions avoidance				
Energy Security	Avoided fossil fuel cost	m USD	2574.50	1915.35	Savings from fuel reduction will further cut import costs of these items.
Social	Social benefits in terms of incomes, health, education, employment and general human well-being from power, connectivity and such additional support infrastructure for the project				Many other indirect social benefits may result from this project. A separate detailed study may be done for exact estimation of the same.

Above Economic analysis shows that, among proposed seven Options, Option 3 seems more economically viable compare to other options, but as per the requirement of the country, site and client to cater livelihood along with this project, Option 7 (recommended option) seems suitable among all.

Hence in this FSR we have considered Option 7 more suitable to the site. However decision is open with the client to choose any Option as per their further requirements.

This economic analysis shows that, the project is having 3E benefit for the country at macro level, which this project can achieve through different means like GHG emissions avoidance, SC-CO2, social benefits, energy security, health benefit and job creation etc.

This project is supporting following SDGs (Sustainable Development Goals):

I. Goal 7 “Clean energy for everyone”: Secure access to affordable, reliable, sustainable and modern energy for everyone.
II. Goal 9 “Industrial and technological innovation and social infrastructure”: By developing robust infrastructure, promote inclusive and sustainable industrialization and also expand technological innovation.
III. Goal 13 “Urgent handling of climate change”: Take urgent countermeasures for climate change and its impact.

Hence such projects should be encouraged to be developed as a pilot for others.

Note: There is further need of detailed study of externalities and benefits of this project.

Grid connection

PGCB requires to ensure adequate and reliable power supply for the upcoming economic zone at Mirsarai in Chittagong, to establish transmission infrastructure for transfer of electricity generated from upcoming coal/LNG power plants at Moheskhali and Matarbari to the major load centers and to meet the rapidly growing demand of residential, commercial and industrial consumers in the southern region (in Gopalganj, Satkhira, Faridpur, Khulna, Chittagong and Greater Barisal Districts), as well as other locations throughout Bangladesh. This GSS can be used for this RE project.

This proposed RE project will be developed in two phases, first phase will be 50 MWac solar PV only and second phase will be remaining of solar PV capacity.

Mirsarai 230 kV GSS of PGCB may be an option for power evacuation but BEZA substation of PGCB (under construction) will be suitable substation for power evacuation of this RE project", based on discussions and suggestion from PGCB.

The various assessed power evacuation and interconnection options are given in chapter 2.

Site connectivity & transportation

Analysis of all the transportation options and consideration of practical aspects, constraints, use and cost, the transportation through road seems more viable in terms of transporting the required materials and equipments etc. and in future the same road can be used by the nearby communities too for their purpose along with the project use.

Following table shows the cost (as per Bangladesh road category type-7) of strengthening of existing west side road of the project location for the project.

Case	Road Width	Road Length	Road Type	Cost of construction
Strengthening of existing road	4.5 m	6.5 KM	Type-7	274.275 lakhs Taka

Following table shows a glance of the recommended Option 7:

The project	200 MWac grid connected solar PV power project (no wind)
Development	In two phases
Owner	EGCBL for Phase-1 and IPP/PPP in Phase-2
Location of plant	Sonagazi upazilla, Dist: Feni, Chittagong Divison, Bangladesh
Geo-coordinates of the site	22^0 47' 13.19" N Latitude and 91^0 21' 59.46" E Longitude
RE technology	Solar PV Plant
Solar technology	Earth mounted Polycrystalline modules of 315 Wp Canadian Solar, Fixed Tilt with central inverter technology
Intended application	Development of clean energy solutions for sustainability of the country in terms of environmental (reduction in GHG emissions), social (environmental and livelihood) and economic (reduction in fossil fuel import) benefits.
Expected project completion period	April, 2019 (Phase-1)

Site specific flooding risk & mitigation measure:

According to the interviews conducted with locals, 25% of the site is almost permanently flooded. The tide regularly intensifies the flooded area to 50%.

Apart from this regular flooding the proposed project area is prone to seasonal inundation during the monsoons. Water from the Feni and Dakatiya rivers often breach the riverbanks and come inside the proposed site. Inputs from locals suggest that water ingress takes places during full moon and maximum water level is around 9-12 inches above ground inside the proposed site. The maximum historical high water level has been 5 meters during the super-cyclone of 1991 (that was an extreme event in the past).

There might be possibilities of such super-cyclones and resultant flooding but these events have had a frequency of 3-4 instances over 50 years.

We have collected last 50 years surface water level (flooding data) from three meteorological measuring stations of BWDB and analysed and forecasted the scenario for coming 25 years.

The Analysis has provided that the maximum possible forecasted surface water level (from all sources of flooding i.e. rain, surge storm, back flooding etc.) which may go is around 4 meter.

These frequent occurrences of flooding events need to be taken into account for the layout of the solar PV plant. Different options for protecting the solar PV plant against floods are assessed such as:

a. Elevated PV plant
b. Floating PV plant
c. Dike for flood protection surrounding the PV plant

The detailed techno-economic analysis has been done for the comparison of “5 m elevated structure” with the “1.5 m elevated structure” following is the comparative result of the analysis:

Development Phase	Cost Parameter	1.5 m elevated solar system with Dike and no livelihood activity beneath panels (m USD/MWdc)	5 m elevated solar system without dike and no livelihood activity beneath panels (m USD/MWdc)	4 m elevated solar system with dike and fishery beneath the solar Panel (m USD/MWdc)
Phase-1 (68 MWdc)	Structure & Foundation Cost (PV system, inverter with each block Transformer)	$0.1159	$0.3977	$0.1729
Phase-2 (168 MWdc)	Structure & Foundation Cost (PV system, inverter with each block Transformer and Pooling SS Power Transformers)	$0.0469	$0.3946	$0.1730

Above analysis result table shows that, cost of structure and foundation for “5m elevated solar system” is around 88% higher compare to “1.5 m elevated solar system”. Hence the option of high elevation of solar PV system is not viable in terms of cost and other above mentioned disadvantages.

Comparative analysis of these possible three flood protection options (based on up to date information, cost analysis and collected and analysed hydrological data of last 50 years from BWDB) shows that the combination of elevated structure (1.5 meter height) and dike (5 meter height) is the most suitable option for the site.

Project site is having two major natural streams, which act in monsoon and flow from populated villages to towards sea coast, passing through the site. These existing natural streams shall be restored with proper embankment at both the sides of these natural streams.

Project risk matrix:

Following table shows the key associated risks to the project and their mitigation measures:

Category of Risk	Risk manifestation event	Allocated to Party	Mitigation
Climate change/ Natural Disaster Risk	Tidal Inundation	Project Developer	The major adaptation measure against flooding in the coastal region of Bangladesh is the construction of earthen dike along the rivers as well as parallel to coastline. The dikes are designed primarily to prevent flooding during high astronomical tides and are found useful during cyclone-generated storm surge too.
	Tropical Cyclones and Storm Surges	Project Developer and Sponsor/Forest Department (Gov. of Bangladesh)	Increasing Dike Height: Dikes obstruct the penetration of surge wave to the land and even if the surge overtops them, the wave energy reduces to a considerable extent. The Project Specific Proposed Dike height has been defined after analysis and assessment of last 50 years historical meteorological stations' data and forecasted for 25 years and regression analysis has been done to arrive at the suitable Dike height. The Coastal Afforestation: In the recent years, plantations in the coastal area as well as along the Dikes are being extensively conducted to enhance flood mitigation measures in the coastal zone by the Forest Department in Bangladesh. This Project will also have the Afforestation along the Dike.
	Coastal Morphological Dynamics (Erosion)	Sponsor/Forest Department (Gov. of	Mangrove Greenbelt: The Government of Bangladesh is now executing the Green Belt Project in the coastal areas. This is a participatory reforestation program aimed at reduction of natural disasters as well

		Bangladesh)	coastal erosion. Afforestation is environment friendly and it helps to stabilize the land and also raise the ground level that will reduce inundation depth. The primary objective of developing mangrove plantations would be to mitigate disastrous effects of cyclones, storm surges and erosion. Several projects with forest management components have been implemented or are currently being implemented in the coastal zone by GoB. Project can leverage those ongoing activities of the GoB for this Mangrove greenbelt development. The Project can have *Sonneratia apetala, Avicenna officinalis, Excoecaria agallocha, Bruguiera gymnorhiza and Nypa fruticans* tree species to be planted (as per Bangladesh Coastal Mangrove Greenbelt/afforestation study and project (Serajuddoula et al. 1995).
	Seismic	Project Developer	The project and its associated infrastructure will be designed and developed considering the applicable zone wise seismic risk and impact.
	Tsunami	Project Developer and Sponsor	Tsunami preparedness — linking to the cyclone preparedness programme: Disaster preparedness, among other activities, includes construction of cyclone shelters and effective warning mechanisms for remote local coastal communities. Most of the cyclone shelters are used as schools during normal periods of the year. Since the project site will be having people living at the site for operation and Maintenance, therefore there is need of development of cyclone shelters and effective warning mechanisms.
Construction risk	Cost overrun	Project Developer	Fixed price, turn-key contract, experienced contractor
	Time overrun	Project Developer	Fixed completion (Date certain) in EPC contract
	Failure to satisfy specified performance	Project Developer	Performance guarantees in TKCC (penalty applicable)
	Delay in connection to grid	Project Developer	To be taken care of in the Power Purchase Agreement (PPA)

	Approvals, permits and Clearances	Project Developer & Governmental Authorities	All the requisite approvals, permits and clearances for the project (Statutory and Non-Statutory) should be obtained by the Project Developer by the appropriate regulating Governmental Authorities. The Governmental Authorities (subject to approval requirements and Project Developer's capacity to provide same, as per contractual stipulations) shall assure issuance. Obtaining all approvals, permits and clearances are a prerequisite for financial closure.
	Completion	Project Developer	Liquidated damages for delay in task/project completion on account of default of the EPC contractor has to be provided in the EPC contract for each component of project procurement.
Technological/Functional risk	Relatively new technology	Sponsor	Full recourse to sponsors until completion
Operational & Management risk	Disruption in production, mal-performance	Operator	O&M contract with incentives and penalties; Operator = Sponsor, incentivized by dividend shortfalls or over-performance
	higher cost than scheduled for instance, migrating sand dunes or higher cost for cleaning	Operator, Sponsors	contingent equity (guarantees) to come up for curing measures (e.g. sand dune walls)
Market risk	Lower sales volume	Power off-taker	Long-term PPA with defined purchase volume OR merchant plant risk, in which case higher equity in project as buffer to banks
	Lower prices	Power off-taker	Long-term PPA with defined prices or merchant plant risk, in which case higher equity percentage as buffer to Lenders
Energy Yield Risk and Solar Resource risk	Less solar irradiation than predicted	Sponsors	Contingent equity injections from Sponsors, that could be used e.g. to enlarge solar field
Financial risk	FX risk	Sponsors/ Lenders	Hedging, local currency funding in debt and equity

	Interest rate risk increases during lifetime of loans	Sponsors	Hedging - mostly mandatory in Project Finance
	Inflation risk	Off-taker	PPA tariff escalated with inflation rate, or anticipation of inflation rate over PPA lifetime (LCOE approach)
		Sponsor	in fixed PPA tariff, risk falls to dividends/equity
Political & Sovereign risk	Changes in law, expropriation	Political Risk Insurance	Political Risk Insurance like OPIC, DIA, Export Credit Agencies (Hermes etc.) and/or Multilateral Development Agency involved (World Bank, Asian Development Bank et.)
	Restricted transfer of Dividends	Sponsors	Political Risk Insurance for Equity
	Expropriation	Sponsors	Political Risk Insurance for Equity
Force Majeure	Earthquake, Tsunami, Thunderstorm, Sand-storms.	Insurance or PPA Off-taker	Force Majeure Insurance or regulation/stipulation in PPA

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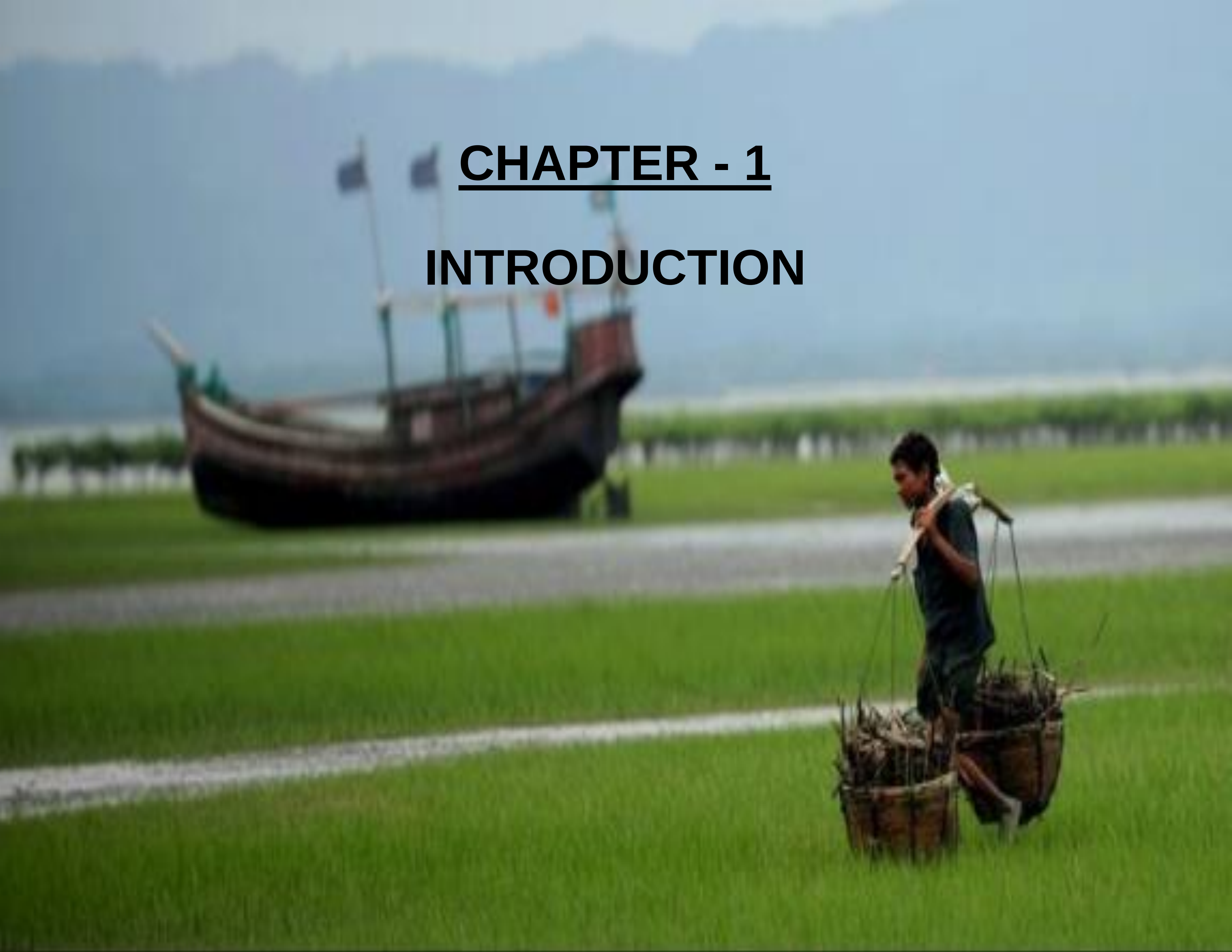
ABBREVIATIONS

Acronym	***Definition***
AC	*Alternating Current*
BOS	*Balance of System*
CAPEX	*Capital Expenditure*
COD	*Commercial Operation Date*
DC	*Direct Current*
DFS	*Detailed Feasibility Study*
DHI	*Diffuse Horizontal Irradiance*
DSRA	*Debt Service Reserve Account*
EIA	*Environmental Impact Assessment*
EPC	*Engineering, Procurement, Construction*
ESIA	*Environmental and Social Impact Assessment*
FC	*Financial Close*
GHI	*Global Horizontal Irradiance*
GI	*Global Irradiation*
IAM	*Incidence Angle Modifier*
ICEC	*International Cost Engineering Council*
IDC	*Interest During Construction*
IFC	*International Finance Corporation, World Bank Group*
IRR	*Internal Rate of Return*
LCOE	*Levelized Cost of Electricity*
MW	*Megawatt*
MY90	*Meteorological Year (values exceeded with a probability of 90%)*
NPV	*Net Present Value*
P50	*(Values exceeded with a) probability of 50%*
POC	*Point Of Connection*
PPA	*Power Purchase Agreement*
PR	*Performance Ratio*
PV	*Photovoltaic*

ROE	*Return on Equity*
SCADA	*Supervisory Control and Data Acquisition*
STC	*Standard Test Conditions*
TMY	*Typical Meteorological Year*
WACC	*Weighted Average Cost of Capital*

CHAPTER - 1

INTRODUCTION



Bangladesh is a low lying country located on the Ganges Delta. 75 % of the country is less than 10 meters above sea level and more than 700 rivers run through its borders. Approximately 162 million people live in a total area of 147,500 square kilometers. Lack of access to modern energy services is one of the reasons for poverty and low economic development. Almost 65.1% of Bangladesh's 162 million citizens live in rural areas.

Different types of power plants generate electricity and synchronize it with the national grid in the Bangladesh. There are some isolated diesel power stations at remote places and islands which are not connected with the National Grid. In the Eastern Zone (eastern side of river Jamuna), electricity is generated from indigenous gas and a small percentage through hydro power.

In the Western Zone, Coal and imported liquid fuel are used for generation of electricity. The fuel cost per unit generation in the Western Zone is much higher than that of the Eastern Zone. Therefore, as a policy, low cost electricity generated in the Eastern Zone is transferred to the Western Zone through the 230 kV East-West Inter connector transmission line.[1]

Electricity is the major source of power for most of the country's economic activities. Only about 74% of the population has access to electricity including about 13% from renewable energy. Total installed electricity generation capacity was 11,265 MW in January, 2015. About 67% of generated power comes from natural gas and the rest is from liquid fuel, coal and hydropower. The present share of renewable energy is only 1.5% i.e. 130 MW through the solar home systems that reached 3.8 million rural households.

The Government of Bangladesh (GOB) has taken a systematic approach towards renewable energy (RE) development including relevant policy and institutional development. As per the National Renewable Energy Policy 2008, the plan is to add generation capacity of 2000 MW by 2020 from renewable sources. EGCBL has identified a potential site to develop an aggregate capacity of 200 MW from solar PV and wind at Sonagazi Upazilla under Feni District. In continuation to this RE deployment in the country, "Power Cell", Power Division, Ministry of Power, Energy, & Mineral Resources (the Client) is carrying out a project "Feasibility Study for Development of Utility-Scale Solar PV and Wind Project Bangladesh" financed and supported by World Bank under the ongoing Rural Electrification and Renewable Energy Development II (RERED II). This project will meet the national renewable energy plan of Bangladesh as outlined in the National Renewable Energy Policy 2008 and will also serve a potential path to avail the RE benefits towards sustainable development of the country.

The Client has appointed Wind Force Management Services Pvt. Ltd. (WFMS) - India in consortium with Suntrace GmbH - Germany and EQMS Consulting Ltd. – Bangladesh through international competitive bidding and tendering process to

[1] http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=18

prepare a feasibility study report for the development of utility-scale solar PV and wind power at Sonagazi Upazilla under Feni District in Bangladesh to address the national renewable energy plan of Bangladesh.

This feasibility study report outlines techno-economic feasibility of setting up Solar PV and Wind Power project at Sonagazi Upazilla under Feni District of Bangladesh.

This report shows the techno-economic feasibility of using different technical concepts of renewable energy (RE) i.e. wind and solar PV technologies to identify the best suitable technological option(s) for the project site.

The objectives of this study are to assess the proposed project site for possible solar PV and wind system installations, estimation of cost, tariff, performance, and site impacts of different RE technology options. In addition, the study explores various development and financing options, ranging from pure public development to public-private partnership (PPP) and independent power producer (IPP) modalities.

Scope of Feasibility study Work

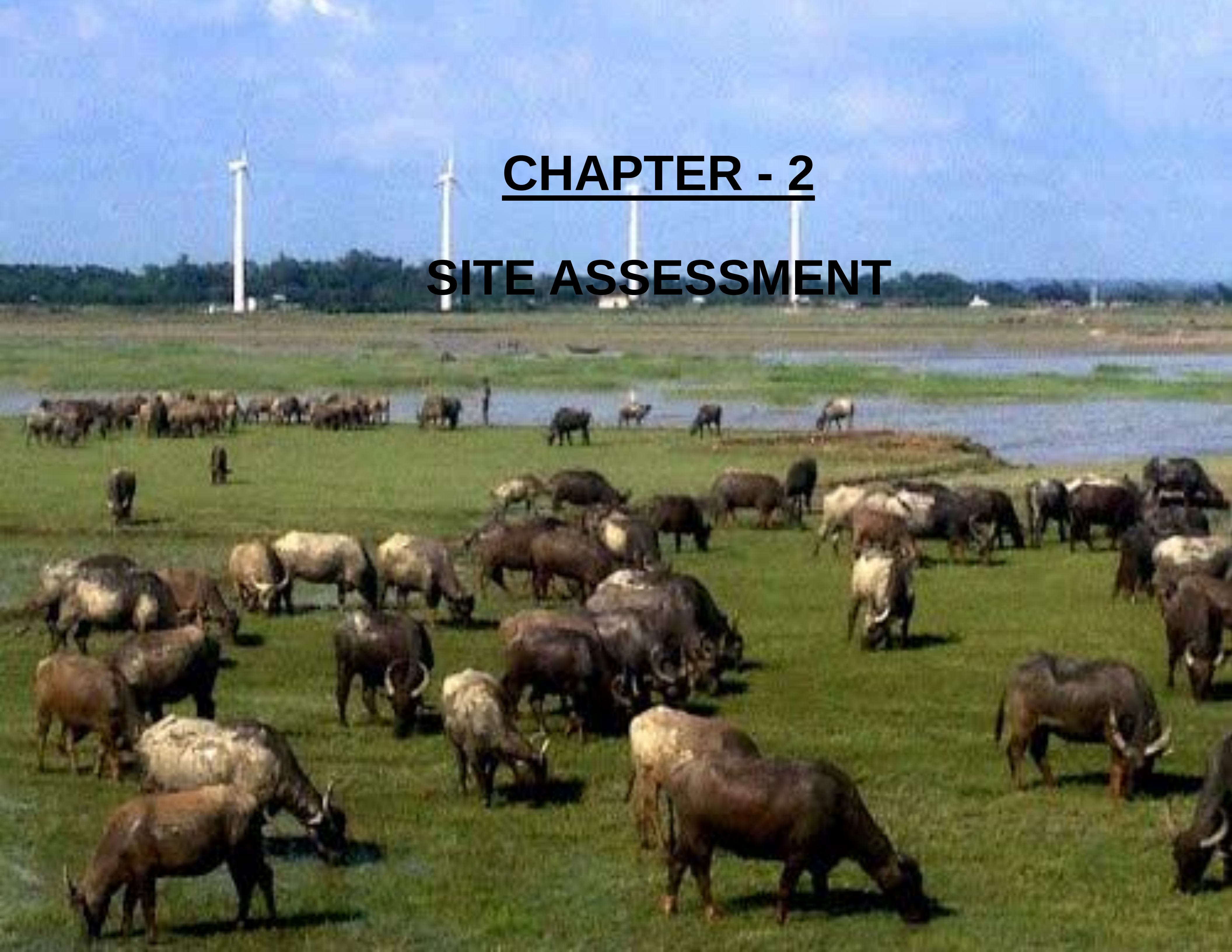
This feasibility study covers followings (as per task 2 of TOR):

- Project site feasibility assessment including topographic mapping of the site, available geophysical, soil, climate, solar and weather data.
- A conceptual design of the project, including estimation of installed capacity.
- Detailed shading analysis
- Estimated energy yields for a number of technologies that are most suitable for the identified sites. (as per TOR)
- The land ownership and land use status assessment.
- Transmission line and grid connection, including cost and potential barriers to achieve grid connection.
- Power off-take options through analysing available existing grid condition.
- The status of roads and accesses, water pipeline, green belt requirement and other associated facilities.
- Permitting requirements and expected timeline and estimated costs for achieving these issues.

- The cost estimates for development, construction and operation of the project and predicted revenue, and cost-benefit analysis for different technological options.
- Financial and economic analysis for the technology suitable for commercial utility-scale grid connected solar power plants at each of the selected sites.
- The investment plan analysis as per TOR
- The estimated local and global environmental benefits including climate, annual GHG reduction benefits attributable to the renewable energy generation for the site.

CHAPTER - 2

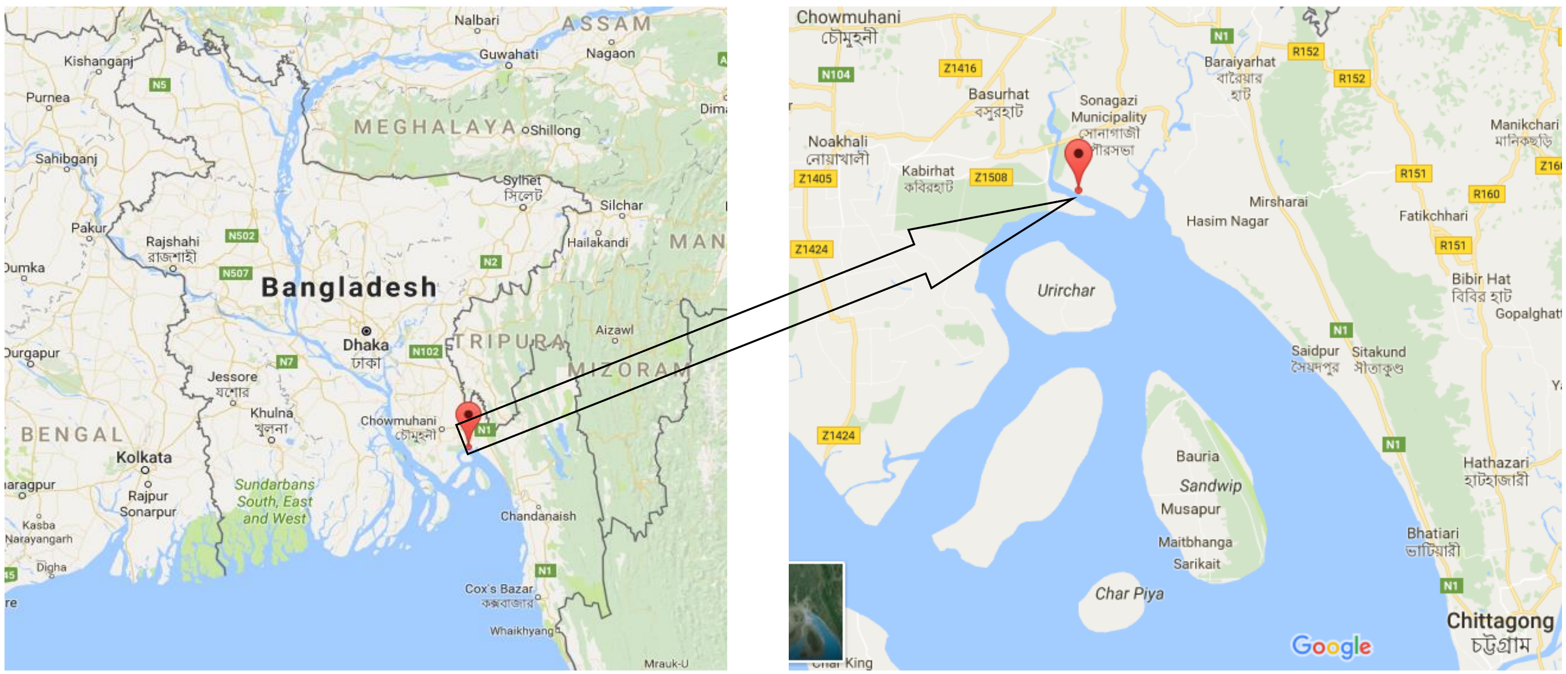
SITE ASSESSMENT



2.1 Site Location

The project is located (as shown in figure 1) on the estuary region between the Feni and little Feni river in the Sonagazi upazilla of Feni district, Chittagong division around 200 KMs south –east of Dhaka.

Figure 1: *Site location map*

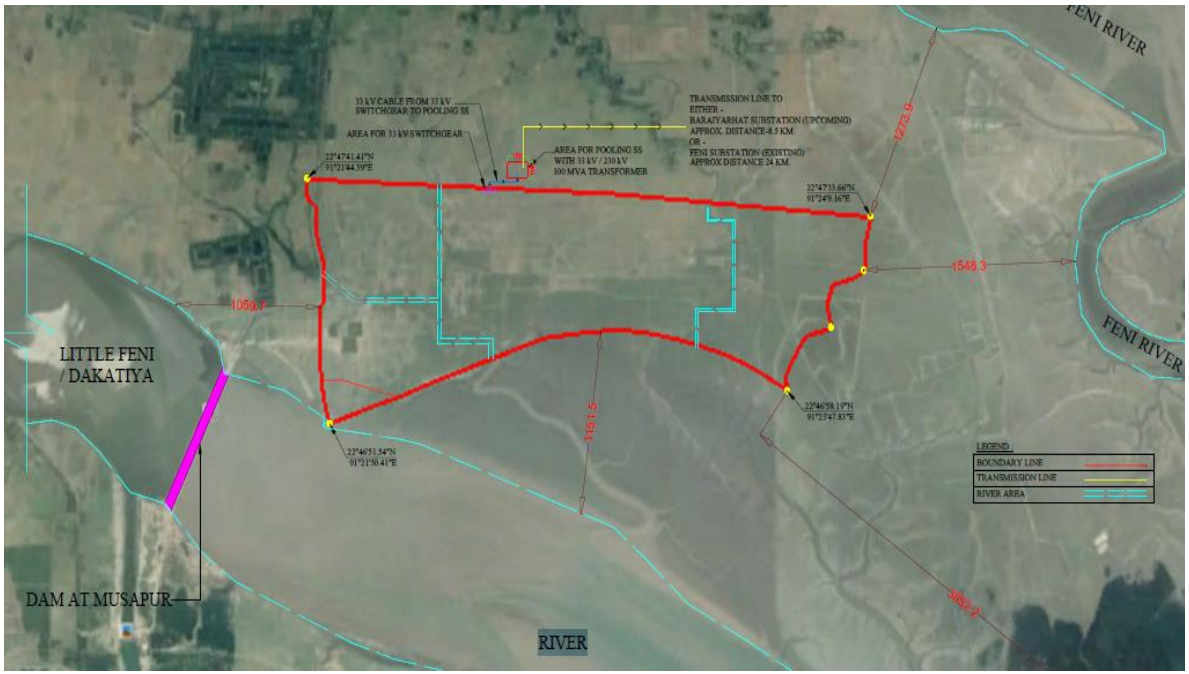


Source: *Google map*

2.2 Site Boundary

The available area of the project site has a size of approximately 1000 acres. Figure 2 shows the boundary of the project site.

Figure 2: *Site boundary*

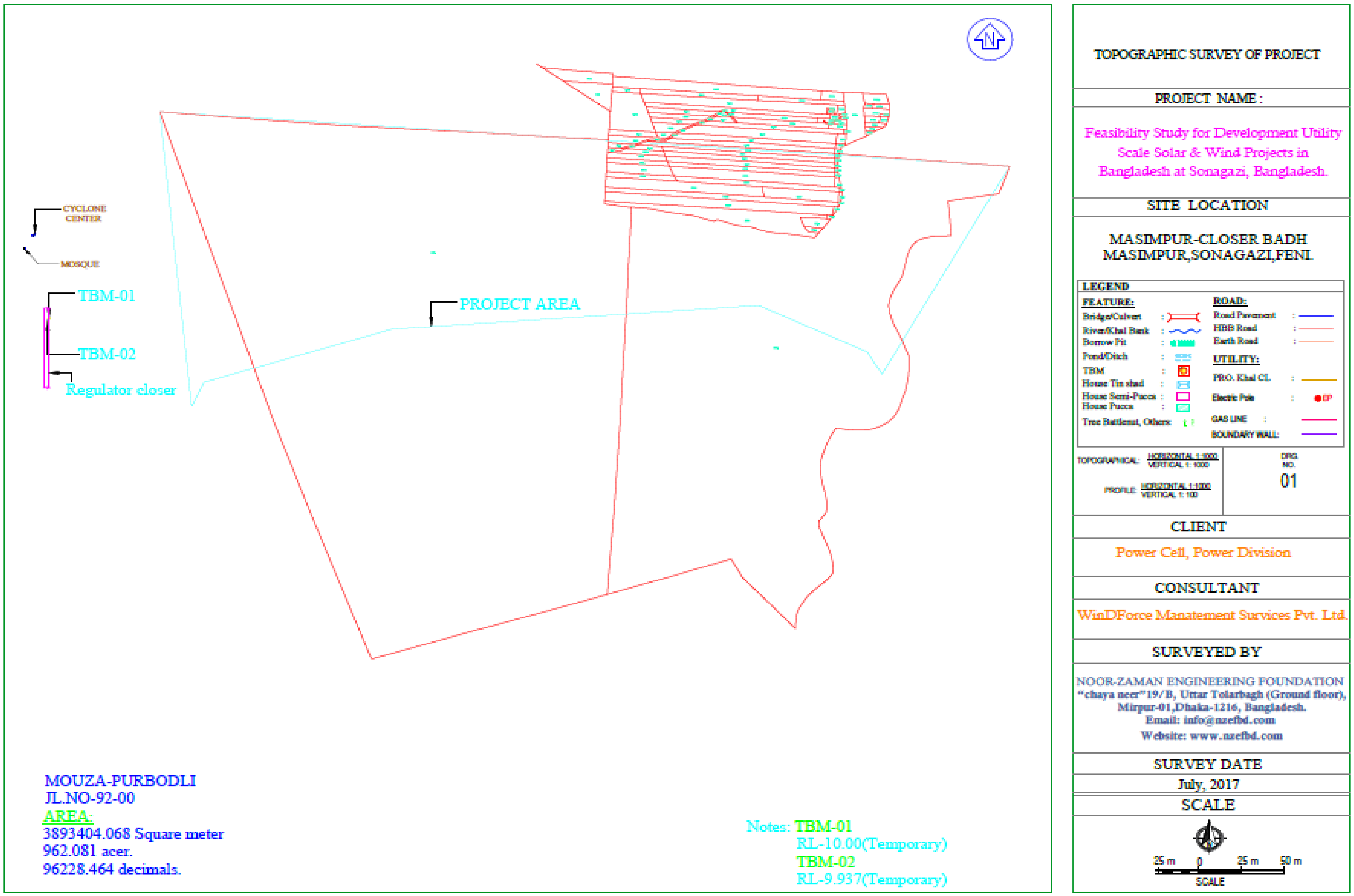


Source: *WFMS*

The site is situated in the eastern region of the little Feni and Feni River and has Feni River on the east, little Feni / Dakatiya River on the west, the Bay of Bengal to the south and villages extending towards Sonagazi municipality on the north.

The consultant appointed the third party to conduct the topographical survey to mark the project boundary and relevant structures. Following topographical figure shows the project site boundary with its Mouja map:

Figure 3: *Topographical map of the project site boundary with mouja map*



Source: *WFMS*

2.3 Site Connectivity

The access to the site is through narrow village roads, the roads are not suitable for continuous heavy vehicle movement. During project construction phase, the EPC contractor will has to strengthen the existing roads or need to develop a new proposed road

Adequate railway connectivity is available up to Feni district. The same railway lines go up to Chittagong which is the major port of Bangladesh and has an international airport too. Using Chittagong airport and port facilities, major equipments can be imported into Bangladesh and these can then be shifted to the site using barges considering the distances and ease of access to site from the river banks.

Alternatively, using railway lines, containerised cargo can be moved to Feni and then taken to the site on truck. This way of material transportation to the site will save time and cost associated with barging in rainy seasons and the cost associated with building up jetties and material handling and storage facilities at the river bank close to the site.

At site, we found adequate high-speed data connection through existing mobile network. For additional bandwidth requirement setting up of VSAT terminals or additional mobile cell sites are recommended.

As per analysis and consideration of practical aspects, constraints, use and cost, the transportation through road seems more viable in terms of transporting the required materials and equipments etc. and in future the same road can be used by the nearby communities too for their purpose along with the project use.

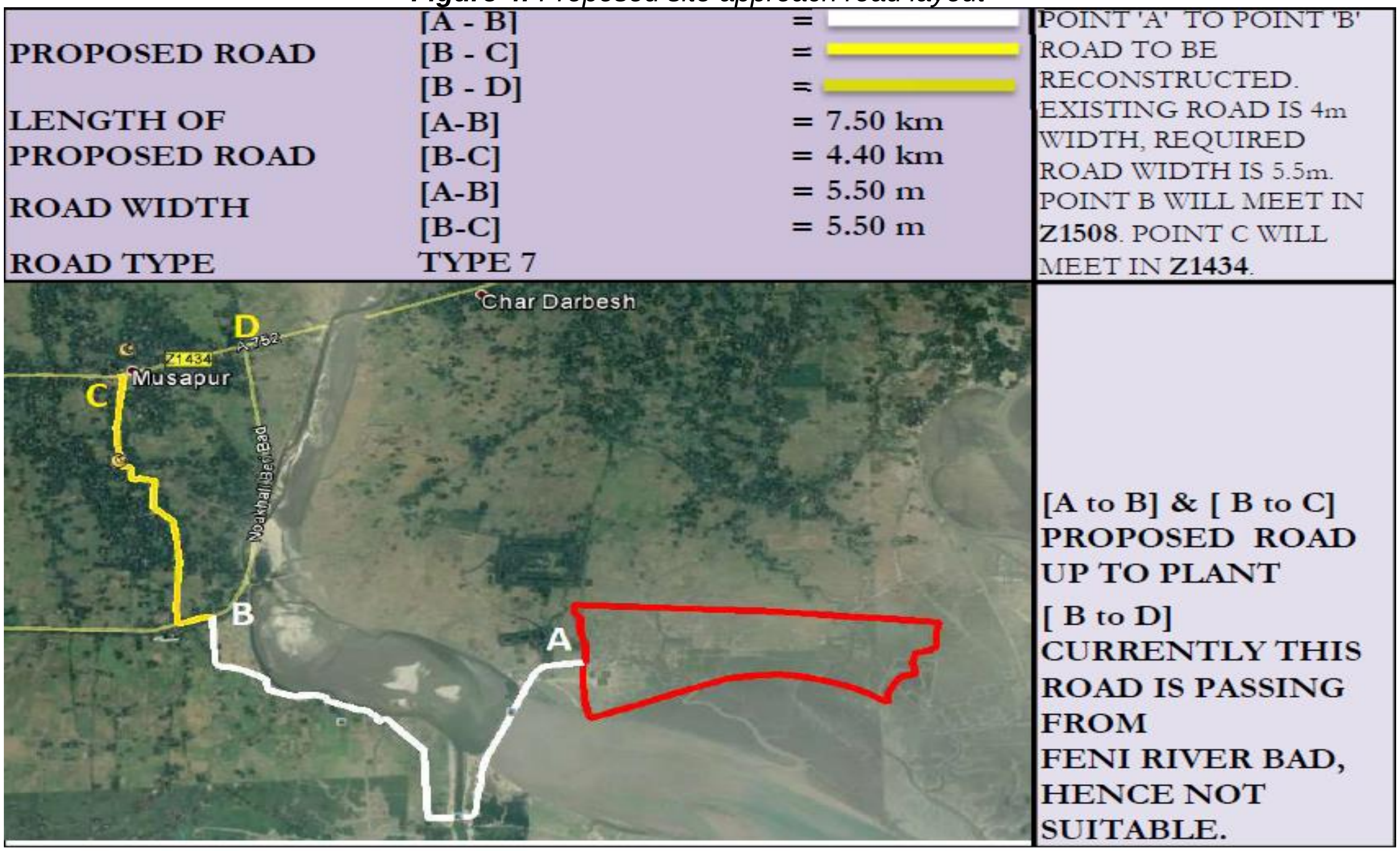
Analysis of all the transportation options and consideration of practical aspects, constraints, use and cost, the transportation through road seems more viable in terms of transporting the required materials and equipments etc. and in future the same road can be used by the nearby communities too for their purpose along with the project use.

Following table shows the cost (as per Bangladesh road category type-7) of strengthening of existing west side road of the project location for the project.

Case	Road Width	Road Length	Road Type	Cost of construction
Strengthening of existing road	4.5 m	6.5 KM	Type-7	274.275 lakhs Taka

Following figure shows the proposed approach road (strengthening of existing west side road:

Figure 4: *Proposed site approach road layout*



Source: *WFMS*

The existing 4 m wide road (from point A to B) is recommended to be strengthening for the project activity as per Bangladesh Type 7 road type.

Following figure shows the associated cost of road strengthening and widening of existing road (from point A to B).

***Figure 5:** Costing of proposed road*

TOTAL COST IN RECONSTRUCTION OF ROAD

ROAD

NAME	LENGTH	WIDTH	AREA	REMARK
A - B	7.50 km	5.50 m	41250.00 sq. m	*PROPOSED ROAD*
B - C	4.40 km	5.50 m	24200.00 sq. m	

NAME	LENGTH	TYPE	COST / km (LAC TAKA)	TOTAL COST (LAC TAKA)	REMARK
A - B	7.50 km	TYPE 7	**31.8**	**274.275**	*WE HAVE CONSIDERED COST AND TYPE OF THE ROAD FROM "ROAD DESIGN STANDARD" "GOVERNMENT OF THE PEOPLES REPUBLIC OF OF BANGLADESH PLANNING COMMISSION" DATED MAY 2004.*
B - C	4.40 km	TYPE 7	**31.8**	**160.908**	*FOR CURRENT SENARIO WE HAVE ASSUMED 15% ECCELARATION FACTOR OVER THE CONSIDERED (COST/ km).*

***Source:** WFMS*

Assessment result and cross section of this approach road is provided in the Annexure I.

2.4 Geography

Sonagazi is located at 22°51′00″N 91°23′30″E / 22.8500°N 91.3917°E . It has 37,184[2] households and a total area of 235.07 km².

[2] https://www.revolvy.com/main/index.php?s=Sonagazi%20Upazila&item_type=topic

It is situated in the southern part of the district, the only Upazila to have a coastline with the Bay of Bengal. Sonagazi is noted for its natural beauty, a sluice gate, known as "Muhuri Project", built in the late 1970s to control water flow of the Feni River is a popular tourist destination as well.

The site soil is primarily alluvial/loamy soil deposited by the river. It is mostly land deposited in the area by the rivers over a long period of time and changing course of the rivers has currently left this area available for cultivation and fishery.

The consultant appointed the third party to conduct the geotechnical investigation of the site, the geotech study report has been used for designing and costing of relevant infrastructure of the project.

The scope of work for soil investigation of the site was as following:

a. Mobilization and Demobilization
b. Drilling boreholes and production of appropriate borehole logs
c. Standard Penetration Tests (SPT's)
d. Undisturbed and Disturbed sampling
e. Laboratory testing of samples & Reporting.

The detailed geotechnical investigation report is separately provided along with this FSR.

Following images show the conducted geotechnical investigation work of the site:

Figure 6: Geotechnical investigation site work

Moisture Content test in Progress

Atterberg Limits test in Progress

Grain size analysis (Hydrometer) test in Progress

Grain size analysis (Sieve) test in Progress

Specific Gravity test in Progress

Direct Shear test in Progress

Source: *WFMS*

2.5 Demography

It is bounded by Feni sadar upazila on the north, Companiganj (noakhali) upazila on the south, Mirsharai upazila on the east, Companiganj and Daganbhuiyan upazilas on the west.

Total population of the upazila is 235,229[3] (urban=12249, rural=222980), male 115680 and female 119549. It has 9 Unions, 94 Mouzas, and 95 Villages with density of 1001 per km^2.

2.6 Water scenario of the site

1.) The site is surrounded by the Feni River to the east and Dakatiya River to the west. Water for usage during civil construction phase can be easily pumped from these rivers.
2.) Additionally, there are minor water bodies within the site area which can be used. During the project's operational stage, water for the O&M e.g. for module cleaning can directly be pumped from the existing water bodies.
3.) Around the site, hand pumps are usually used to draw groundwater (as per land revenue and irrigation department officials of the local UNO). Since the water table is as high as 6 meters from the surface therefore setting up multiple shallow bore wells for module cleaning system can be done.
4.) Considering site location and salinity of the site being coastal area, automatic dry type robotic module cleaning can also be an option (for further details refer section 5.5 of this FSR).

2.7 Natural disaster risks

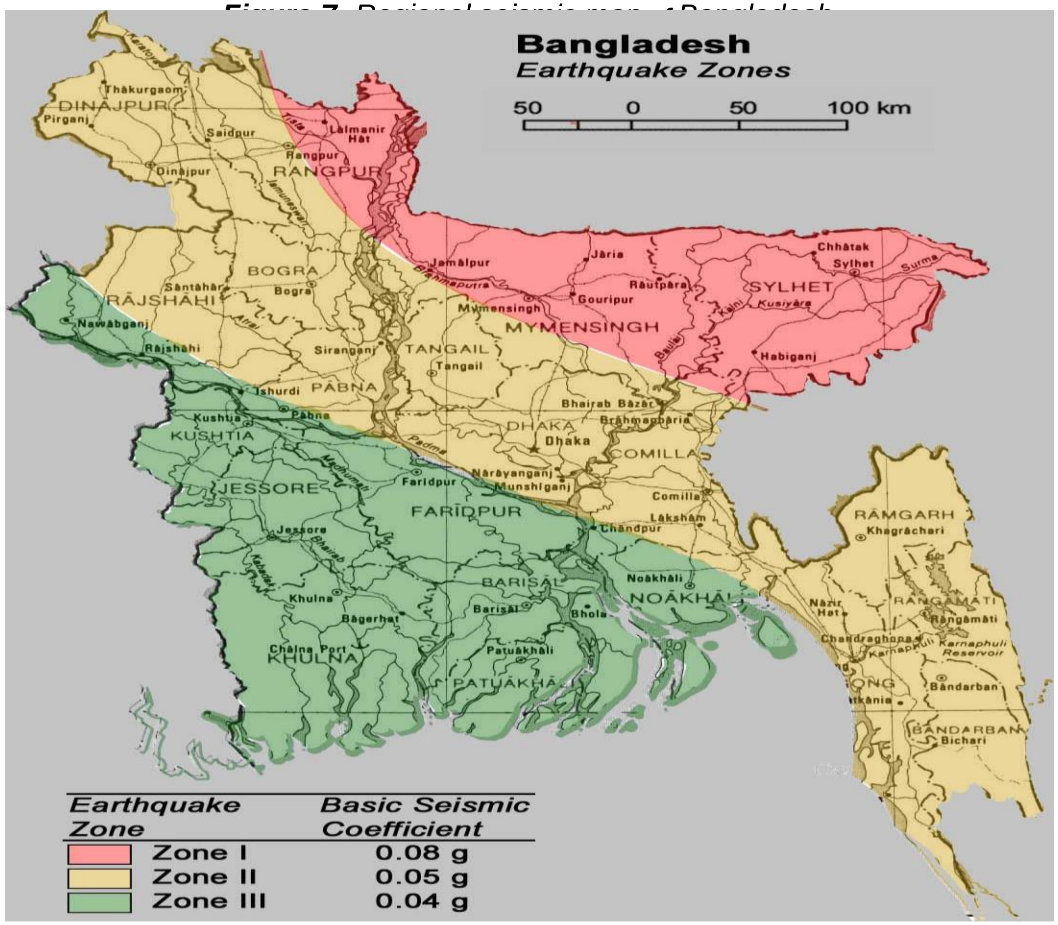
2.7.1 Seismic zone / risk

Thirty-five percent of the Bangladesh sits on top of actively deforming region, including the capital of Bangladesh, Dhaka, with 16 million people living in its metropolitan area. In addition, this fold belt extends into western Myanmar and north-eastern India. These observations raise the possibility that detachments may be capable of producing earthquakes with severe ground shaking. This is particularly worrisome because detachments form some of the largest faults on Earth, underlying many populated basins, including 35% of Bangladesh.

Following figure shows the regional seismic map of Bangladesh:

[3] http://en.banglapedia.org/index.php?title=Sonagazi_Upazila

Figure 7: Regional seismic map of Bangladesh



***Source:** Google*

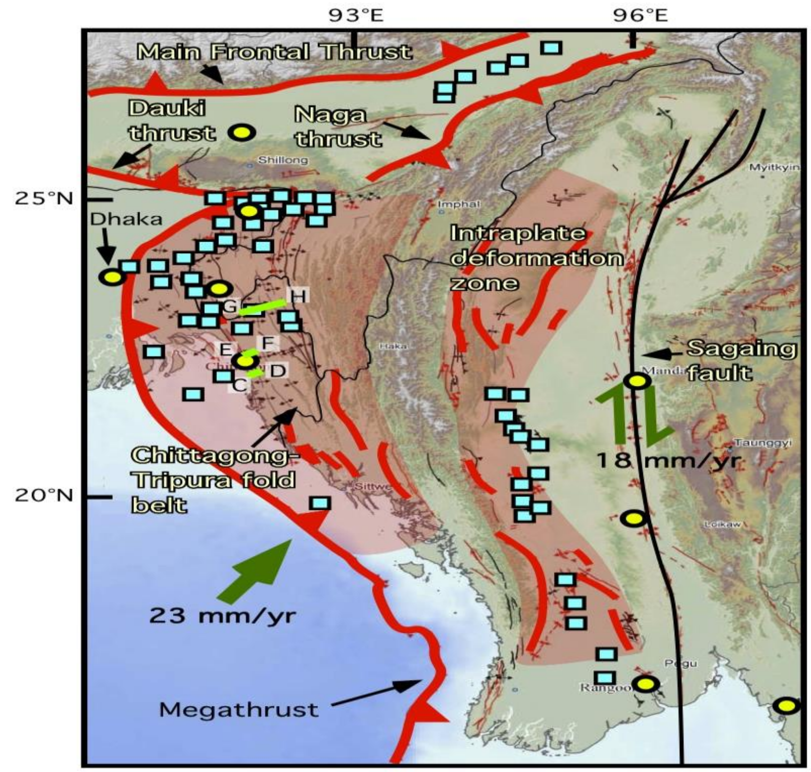
Above figure shows that the proposed project site comes under Seismic Zone II (Moderate risk) therefore during project development this seismic effect should be considered in design and development.

The Chittagong-Tripura fold belt poses a further concern because it extends offshore. A large thrust event occurring offshore could potentially produce a regionally important tsunami with very little warning time for coastal residents.[4]

However, many factors have to work at the same time for occurrence of such tsunami, said the experts. “If such a tsunami is caused, it would hit Bangladesh coast within 20 minutes and it would be dangerous for the country due to the vast extent of the low elevated coast plain,” said ASM Maksud Kamal, national expert, Earthquake and Tsunami Preparedness project.

Aftab Alam Khan, a leading geologist of the country, said, “Analysing the tectonic and geographic conditions of the Bay of Bengal, I find very low possibility of a tsunami here. But massive submarine landslide may occur due to earthquake in the Bay of Bengal what would be destructive for the country's coastal belt due to sea turmoil.”[5]

Figure 8: *Tripura Chittagong fault line*



Source: *www.earthobservatory.sq*

[4] http://www.earthobservatory.sg/project/bangladesh-active-faults-chittagong-tripura-fold-belt)

[5] http://www.thedailystar.net/news-detail-3917

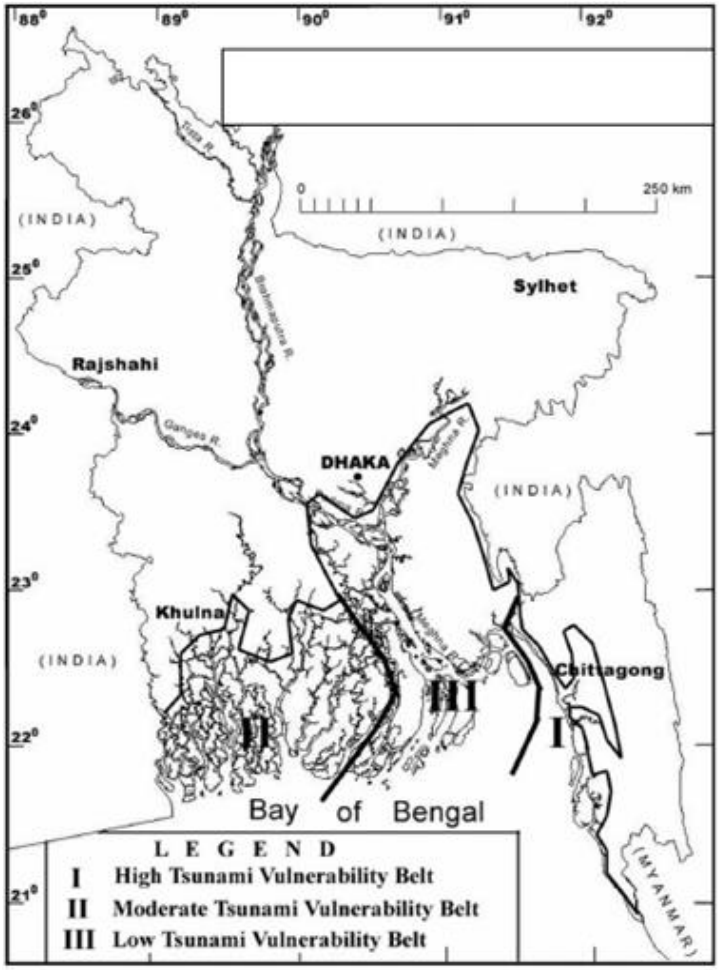
Following figure 6 shows Tsunami Vulnerability Map of Bangladesh and it shows that the proposed project site comes under the *"III Low Tsunami Vulnerability Belt"*.

Tsunami Vulnerability Coastal Belt III of the Barisal–Sandwip estuarine coastline — Low vulnerability. The estuarine coastal belt is considered to be less vulnerable due to the presence of numerous islands and shallow mudflats in the upper regime of the continental shelf.

The benefits of establishing set-back zones along the coast are well-recognized and practiced around the world. There are different ranges of set-back zones in different countries (8–3 000 meters) India has adopted a 500-metre set-back zone. Bangladesh is also considering the establishment of set-back distances along the coastline. This will restrict certain uses, such as the construction of residential blocks and hotels within a specified distance. In the absence of set-back distances, hotels and other infrastructures are being indiscriminately built on the beaches of Cox's Bazar, St Martin's Island and other locations. For the Bangladesh coast, a set-back distance of 50 meters in general, 100 meters for non-polluting industries and 200 meters for polluting industries can be considered.[6]

In this feasibility assessment and designing Seismic and Tsunami risks have been considered, however during actual project development there is further need of detailed natural hazard risks assessment to be considered in the designing and development of the project.

Figure 9: *Tsunami Vulnerability Map of Bangladesh*



Source: *http://www.fao.org/docrep/010/ag124e/AG124E05.htm*

6 http://www.fao.org/docrep/010/ag124e/AG124E05.htm

2.7.2 Flood hazard:

Floods in Bangladesh occur for number of reasons. The main causes are excessive precipitation, low topography and flat slope of the country; but others include:

- The geographic location and climatic pattern: Bangladesh is located at the foot of the highest mountain range in the world, the Himalayas, which is also the highest precipitation zone in the world. This rainfall is caused by the influence of the southwest monsoon. Cherapunji, highest rainfall in the world, is located a few kilometres north east of the Bangladesh border
- The confluence of three major rivers, the Ganges, the Brahmaputra and the Meghna: the runoff from their vast catchment (about 1.72 million km^2) passes through a small area, only 8% of these catchments lie within Bangladesh. During the monsoon season the amount of water entering Bangladesh from upstream is greater than the capacity of the rivers to discharge in to the sea.
- Bangladesh is a land of rivers: there are about 310 major and minor rivers in the country. The total annual runoff of surface water flowing through the rivers of Bangladesh is about 12,000 billion cubic meters.
- Man-made environment: the construction of embankments in the upstream catchments reduces the capacity of the flood plains to store water. The unplanned and unregulated construction of roads and highways in the flood plain without adequate opening creates obstructions to flow.
- The influence of tides and cyclones: the frequent development of low pressure areas and storm surges in the Bay of Bengal can impede drainage. The severity of flooding is greatest when the peak floods of the major rivers coincide with these effects.
- Long term environmental changes: climate changes could influence the frequency and magnitude of flooding. A higher sea level will inhibit the drainage from the rivers to the sea and increase the impact of tidal surges. Deforestation in hilly catchments causes more rapid and higher runoff, and hence more intense flooding.

The springtides of the Bay of Bengal retard the drainage of floodwater into the sea and locally increase monsoon flooding. A rise of MSL at times during the monsoon period due to effect of monsoon winds also adversely affect the drainage and raise the flood level along the coastal belt.

2.7.2.1 Heavy Precipitation

Extreme rainfall can create flooding in the project area. A study by Ahammed, published in 2014 shows the historical and forecasted maximum rainfall daily as shown in the table 1 and 2 below.

Table 1: *Forecasting of annual daily maximum rainfall for the period of 2010 to 2066 (Dhaka)*

Annual daily maximum rainfall (mm)	Z	F(z)	P(z)	Frequency (n)
200	0.816019	0.7939	0.2061	12
225	1.204821	0.8849	0.1151	7
250	1.593624	0.9452	0.0548	3
275	1.982426	0.9767	0.0233	1
300	2.371229	0.9911	0.0089	1

Source: *Researchgate*

Table 2: *Historical extreme rainfall events of Dhaka*

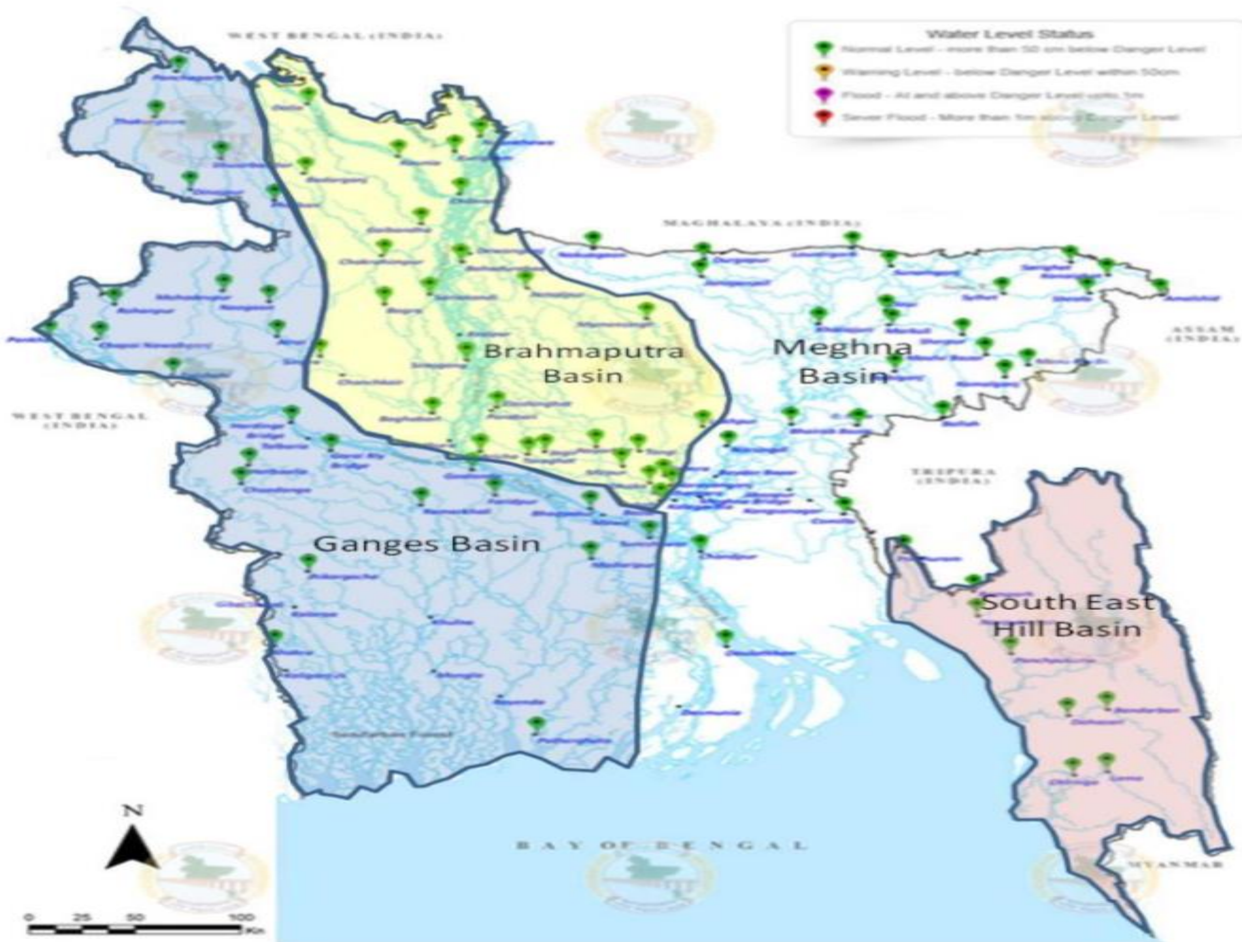
Rank	Date	Daily rainfall (mm)
1	September 14, 2004	341
2	July 28, 2009	333
3	July 14, 1956	326
4	September 16, 1966	257
5	July 22, 1971	251
6	May 25, 1972	231
7	June 05, 2008	190
8	June 19, 1963	189
9	June 21, 1961	185
10	September 12, 2006	185

Besides, the annual flood reports from 2012 to 2014 of the Bangladesh Water Development Board have been reviewed and the following maximum precipitations per day and month have been found:

- Maximum precipitation per day: 373 mm (June 2012; South East Hill Basin, Chittagong)
- Maximum precipitation per month: 790 mm (May 2013; Meghana Basin)

Following figure shows the South East Hill Basin and Meghan Basin:

Figure 10: *Tripura Chittagong fault line*



Source: *Annual Flood Report 2014, FFWC, BWDB*

We have collected last 50 years rain fall data in mm per day from CL358 meteorological measuring station of Bangladesh Water Development Board (BWDB) and analysed the data (that is more site specific compare to above mention for Meghna basin data from Annual Flood Report 2014).

Out of these last 50 years data, 13 May 1984 has the maximum occurred precipitation data i.e. 280.20 mm per day. If we conservatively consider that, the same rate of rain fall continuously occur for 4 days then the project site can collect the 1.12 meter of water level within the site (considering the Dike around the periphery).

The Analysis has provided that the maximum possible water logging within the project site can be 1.12 m because of this maximum continuous rain fall for 4 days.

Result of the precipitation data analysis is provided in the Annexure E.

Besides precipitation, the possibility of ground water entering the diked area must be considered. Therefore following can be Possible solutions:

- Shaping the terrain → slopes
- Drainage
- Pumps
- System, Electrical parts and components (Solar system, connectors, combiner boxes, inverters, transformers, communication system, and meteorological station) should be installed at a minimum height of 1.5 m.

2.7.2.2 Seasonal inundation during the monsoons

According to interviews with locals 25% of the site is almost permanently flooded. Tide regularly increases the flooded area to 50%.

Apart from this regular flooding the proposed project area is prone to seasonal inundation during the monsoons. Water from the Feni and Dakatiya rivers often breach the riverbanks and come inside the proposed site. Inputs from locals suggest that water ingress takes places during full moon and maximum water level is around 9-12 inches above ground inside the proposed site. The maximum historical high water level has been 5 meters during the super-cyclone of 1991 (that was an extreme event in the past).

There might be possibilities of such super-cyclones and resultant flooding but these events have had a frequency of 3-4 instances over 50 years.

We have collected last 50 years surface water level (flooding data) from three meteorological measuring stations of BWDB and analysed and forecasted the scenario for coming 25 years.

The Analysis has provided that the maximum possible forecasted surface water level (from all sources of flooding i.e. rain, surge storm, back flooding etc.) which may go is around 4 meter.

Result of this surface water level (flooding) analysis is provided in the Annexure H.

These frequent occurrences of flooding events need to be taken into account for the layout of the solar PV plant. Different options for protecting the solar PV plant against floods are considered such as:

d. Elevated PV plant
e. Floating PV plant
f. Dike for flood protection surrounding the PV plant

a. Elevated PV plant

The advantages of applying an elevated PV plant are:

- to allow for alternative use of the land (e.g. farming and cattle breeding)
- avoidance of direct contact of sensitive components with brackish water

Elevated mounting structure is considered as not a reasonable option because of following reasons:

- Because of brackish water coming into the site approx. 4 months every year, the benefit of agricultural use is limited and vegetation is poor.
- Marine grade steel frames or concrete foundations must be used which would increase the CAPEX.
- Corrosion might be a major problem. Additional costs for adapting the components (inverters, transformers, combiner boxes, connectors) to the saline environment have to be taken into account and a proper installation has to be ensured to avoid downtimes of the plant and additional operation and maintenance costs.

- Manufacturers might not provide approval for mounting their components on a site flooded with brackish water. Official approvals from manufacturers are needed to avoid problems regarding warranty claims at a later time.
- All electrical parts of the plant including modules, combiner boxes, inverters, transformers and switchgears etc. would require an elevated supporting structure.
- The height and static of the elevated structure has to account also for extreme flooding events to avoid any damages on the equipment.
- During the presence of flooding events, the maintenance of the equipment would be only possible to a limited extent.
- For maintenance work on the inverter stations, ladders would be necessary to allow adequate access to the platforms.
- Maintenance work on the combiner boxes, modules and mounting structure would require mobile platforms with ladders.
- Module cleaning would be possible mainly during non-flooding periods however, it would require special equipment like mobile platforms with laddars to reach the elevated solar PV arrays.
- The installation of the plant would have to be carried out in parts on flooded terrain due to the regular flood tide. Extra costs for difficult transport and assembling conditions, construction site road, safety measures etc. would have to be considered.

The Consultant has elaborated a scenario considering an elevated mounting structure of 5.0 meters for the PV array and electrical equipment such as inverters, transformer, and combiner boxes, for flood protection and compared it against a dike along the complete project site borders. This comparison is based on the 100 MW_{AC} reference case technical layout (based on fixed-tilt solar PV system with central inverter and polycrystalline module technology), as shown in the table below.

Table 3: *Comparison of elevated structures as flood protection measure against a dike*

Parameter	Unit	Diked PV plant	Elevated PV plant
Plant capacity	MW_{AC}	100	100
Peak capacity	MW_{DC}	136	136
Energy Yield	GWh/a	202.02	202.02
Cost for structures and foundations#	USD / MWp	116 442	399 294
Cost for dike (10.8 km)$	M USD	23.32	0
CAPEX	M USD	157.77	171.87
OPEX	M USD	1.78	2.23

LCOE *	USD cents/kWhr	10.1	11.2

*****Concessional finance conditions*

 # Refer Annexure k

$ Refer Annexure of Dike design

It can be seen that due to the higher cost required for the elevated structures and respective foundations, the elevated PV plant is less attractive in terms of LCOE when compared to the option considering a dike instead. Higher cost and risk are the principle reasons to exclude the only higher elevated PV system from further analysis.

We have collected the last 50 years rain fall data in mm per day from Bangladesh Water Development Board (BWDB) of CL358 meteorological measuring station of BWDB and analysed the data.

Out of these last 50 years data, 13 May 1984 has the maximum occurred precipitation data i.e. 280.20 mm per day. If we conservatively consider that the same rate of rain fall continuously occur for 4 days then the project site can collect the 1.12 meter of water level within the site (considering the Dike around the periphery).

The Analysis has provided that the maximum possible water logging within the project site can be 1.12 m because of this maximum continuous rain fall for 4 days (considering without any provision of pumping, in worst case), therefore the analysis shows that the solar panel should be elevated at the height of in between 1.5 to 2 meter (we have considered 1.5 m height of the structure to be elevated along with 5 m Dike around the periphery with pumping arrangement in our Options).

As per this analysis we have assessed the requirement of pumping for discharging this logged rain water from the project site to the outside the boundary, the installation of pumps is matter of further detailed study during the project development.

Result of the precipitation data analysis is provided in the Annexure E.

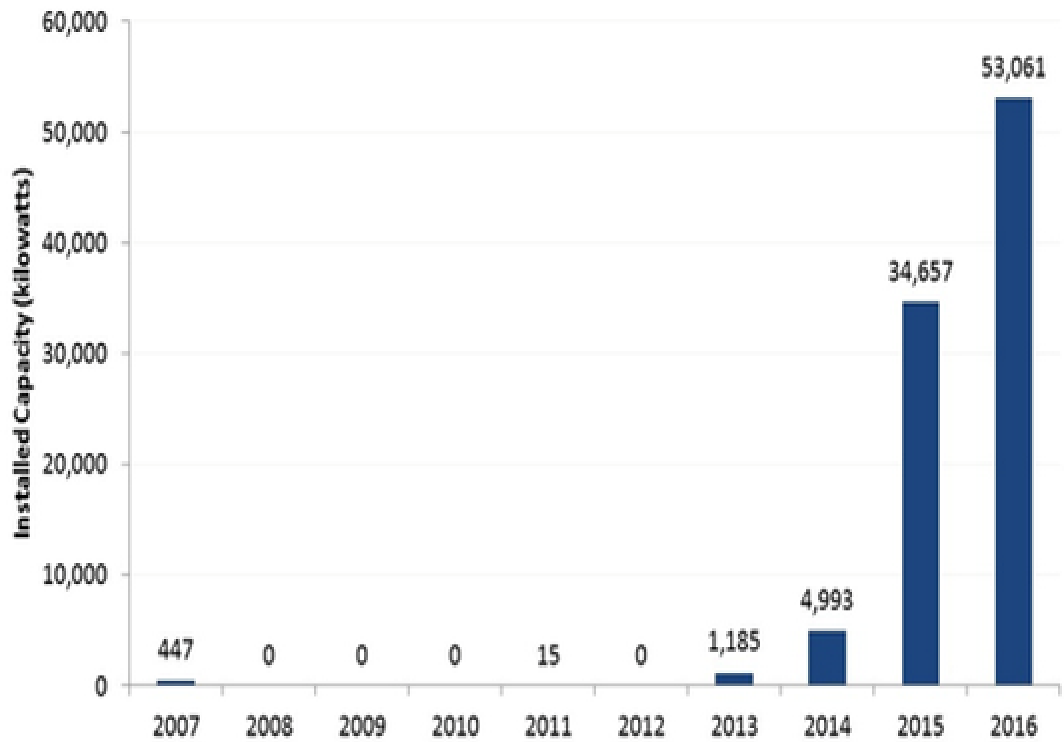
Result of this pumping requirement assessment is provided in the Annexure F.

Figure 11: *Global floating PV capacity installed by year*

b. Floating solar PV plant

An emerging trend in the field of solar energy is the idea of allowing PV modules to float on water bodies instead of using precious land. This is majorly of importance to the countries with lack of space. The idea is of a floating mounting system, which has a framing structure equivalent to a standard ground- mounted PV system that is used to support the PV modules above the water.

The following figure 11 shows the global floating PV capacity installed per year. It is clearly seen from the graph that this technology is in its nascent phase. However, there have been a few pilot projects commissioned in Japan, USA, India, Australia, and Brazil. All the projects, as of now, have been materialized on fresh water bodies.



Source:

https://www.nrel.gov/tech_deployment/state_local_governments/blog/floating-solar-photovoltaics-gaining-ground)

Table 4: *Advantages and disadvantages of floating systems*

Advantages	Disadvantages
Saves land	Requires special components designed specifically for offshore applications (corrosion resistant and waterproof-marine grade)
Increased production due to natural cooling effect (approx. 11%)	Operation and maintenance is a challenge
Increased production because of reflections on the water	More expensive than ground mounted
Reduces the evaporation of water (about 70%) and algae formation	Reluctance of module and inverter manufacturers to provide warranties
No proven negative impact on the ecology	Technology is yet to prove itself in salt water bodies
	Less production because of set inclination of modules with small angle
	Limited experience - no utility scale project has been realized so far

The major projects have used the Hydrelia technology of Ciel et terre. The individual solar panels are clipped onto specially designed air-filled floats, which are assembled to form a large raft. The raft is assembled on the shore and pushed out onto the reservoir in sections. Boats are used to position the raft's sections, and then they are attached to buoys on the water's surface, which are anchored to the bottom of the reservoir to keep the installation in place.

Figure 12: *Floating solar plant of 1008 kWp located near Ono city, Japan*

The solar PV panels on the floating array are connected via a submerged cable to inverters onshore. The electricity produced by the panels is carried to shore using marine cable, ensuring it is protected from the water. The floating platforms are recyclable, utilizing high-density polyethylene, which can withstand ultraviolet rays and corrosion.

The following aspects increase the cost of floating PV plants: mounting structure, the price of marine grade components (e.g. PV modules, cables, combiner boxes, inverters), higher assembling costs. The overall CAPEX tends to be 30 to 40 % higher.

Source: *http://www.ciel-et-terre.net/*

Floating solar PV installation is considered as not a reasonable option because of the following reasons:

- The floating PV systems are designed for lakes and water ponds with a permanent water level above ground. For this project, most of the time the project site is expected to be dry. So far just one project for such an application is known and no research/study has been carried out in analysing the effect on the PV plant and the ground after the flood is gone (variation of ground level and alignment of the PV modules).
- Corrosion will be an enormous issue on this specific site, as floating PV plants up to now were almost exclusively built on fresh water and the technology is yet to prove itself in salt-water bodies. Despite of the availability of waterproof-marine grade components, serious problems on large (inverters) as well as on small components (connectors) might arise and lead to significant downtimes of the plant.

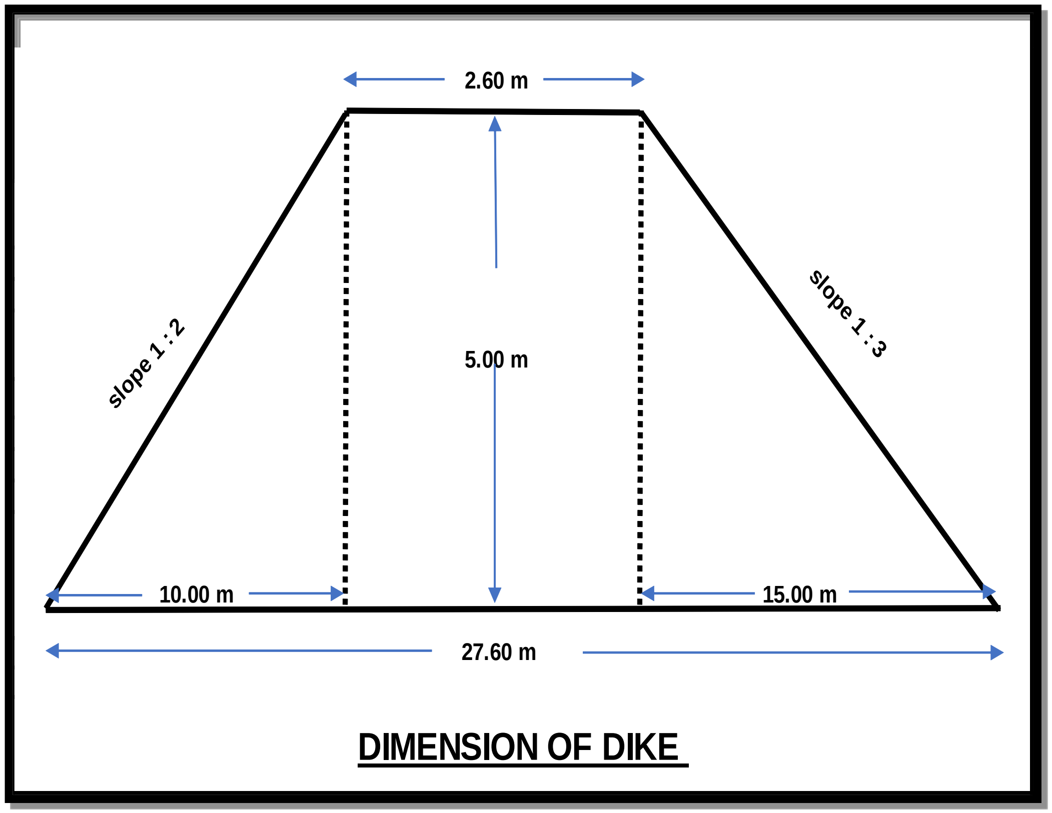
- The heavy electrical equipment of the plant including inverters, transformers and switchgears etc. would require an elevated supporting structure also allowing adequate access for maintenance work. These components would have to be installed on shore resulting in higher cabling costs and energy losses.

c. Dike for flooding protection

Dike system around the solar PV plant is considered as a preferred option for the project because of following reasons.

- The dike could be constructed along the borders of the site and be connected to the existing dike (elevated street) located at the western boundary of the project site.
- The dike would allow designing, constructing and operating the solar PV plant on a dry area during the whole year. However, water entering the dike area during regular rainfall (in particular during monsoon season) and flooding events has to be considered for the design of the solar PV plant.
- The expected cost for the dike is considered as moderate compared to other options. As first indication, the cost for a dike with a height of 5.0m is estimated to be around 2.07 m USD/km dike.

Figure 13: *Exemplary cross section of a dike*



Source: *WFMS*

Prepared Cross section of the proposed dike is provided in the above figure.

Result of this Dike requirement assessment is provided in the Annexure G.

We have collected the last 50 years Surface water level (flooding data) from three meteorological measuring stations of BWDB and analysed and forecasted the scenario for coming 25 years.

The Analysis has provided that the maximum possible forecasted surface water level (from all sources of flooding i.e. rain, surge storm, back flooding etc.) which may go is around 4 meter, therefore the suggested 5 meter height of the Dike is sufficient to accommodate the maximum possible predicted surface water level (as per this feasibility study, however for this site the detailed subject study should be carried out by the third party during development phase).

Result of this surface water level (flooding) analysis is provided in the Annexure H.

Conclusion for Flood Hazard

The detailed techno-economic analysis has been done for the comparison of "5 m elevated structure" with the "1.5 m elevated structure" following is the comparative result of the analysis:

Table 5: *1.5 m and 5 m elevated solar system comparative costing*

Development Phase	Cost Parameter	1.5 m elevated solar system with Dike and no livelihood activity beneath panels (m USD/MWdc)	5 m elevated solar system without dike and no livelihood activity beneath panels (m USD/MWdc)	4 m elevated solar system with dike and fishery beneath the solar Panel (m USD/MWdc)
Phase-1 (68 MWdc)	Structure & Foundation Cost (PV system, inverter with each block Transformer)	$0.1159	$0.3977	$0.1729
Phase-2 (168 MWdc)	Structure & Foundation Cost (PV system, inverter with each block Transformer and Pooling SS Power Transformers)	$0.0469	$0.3946	$0.1730

Above analysis result table shows that, cost of structure and foundation for “5m elevated solar system” is around 88% higher compare to “1.5 m elevated solar system”. Hence the option of high elevation of solar PV system is not viable in terms of cost and other above mentioned disadvantages.

Comparative analysis of these possible three flood protection options (based on up to date information, cost analysis and collected and analysed hydrological data of last 50 years from BWDB) shows that the combination of elevated structure (1.5 meter height) and dike (5 meter height) is the most suitable option for the site.

Appendix D shows the impacts and mitigation measures (Tidal Inundation, Cyclones & Storm Surges and Erosion) for sea level rise in the Bay of Bengal of Bangladesh (the Project site comes under this area).

Project site is having two major natural streams, which act in monsoon and flow from populated villages to towards sea coast, passing through the site. These existing natural streams shall be restored with proper embankment at both the sides of these natural streams.

2.8 Grid connection

Based on the information gathered during the site visit and subsequent discussions with:

- The local Power Grid Company of Bangladesh,
- Officials at the sub-stations including
- Assistant General Manager (AGM) of Palli Bidyut Samiti

Following three interconnection options have been considered for this project:

1.) Feni 132 kV Sub-Station of PGCB: PGCB is having exiting 132 kV Feni Sub-Station (SS), that is an existing option which can be considered for capacities less than 80 MWac, but the following points make it difficult to connect this project (>80 MWac) to this SS.

  - It is 132 kV SS and it can only be used for capacity less than 80 MWac beyond 80 MWac there is need of 230 kV SS.
  - Lack of additional space for bay extension and switch-gears in the existing Feni SS of PGCB.

- 132 kV lines from the site has to pass through heavily populated area and there would be considerable difficulty in getting rights of way for setting up of transmission towers for the project. The cost and time associated with getting clear title deeds and rights of way for setting up the dedicated PE capacity would push back the project completion and commissioning by a considerable margin.

Distance from the proposed project site to Feni SS of PGCB is around 24 KMs and the cost associated with setting 132 KV lines for this distance would be high and should be taken up only if there are no alternative interconnectivity points available.

2.) Baraiyaarhaat 132 kV Sub-Station: This option is relatively simpler because of the following points:

- The SS is in construction stage and any plans of feeding an additional 124 MWac power can be easily considered at the execution stage itself (considering expansion in capacity of this SS to 230 kV) or less than 80 MWac power plants can be fed into this 132 kV SS.
- The distance from Baraiyarhat to the project site is around 10 KMs and along thinly populated area, therefore, putting up transmission towers would be relatively easy.
- The SS is being up as part of the 7th 5-year plan of PGCB and any additional funds required for setting up bay extensions dedicated to the renewable energy project can be shared by PGCB and the project developer.

3.) Mirsarai 230 kV SS: This SS is under construction and targeted commissioning by April 2018.

PGCB requires to ensure adequate and reliable power supply for the upcoming economic zone at Mirsarai in Chittagong, to establish transmission infrastructure for transfer of electricity generated from upcoming coal/LNG power plants at Moheskhali and Matarbari to the major load centers and to meet the rapidly growing demand of residential, commercial and industrial consumers in the southern region (in Gopalganj, Satkhira, Faridpur, Khulna, Chittagong and Greater Barisal Districts), as well as other locations throughout Bangladesh. This GSS can be used for this RE project.

This proposed RE project will be developed in two phases, first phase will be 50 MWac solar PV only and second phase will be remaining of solar PV capacity.

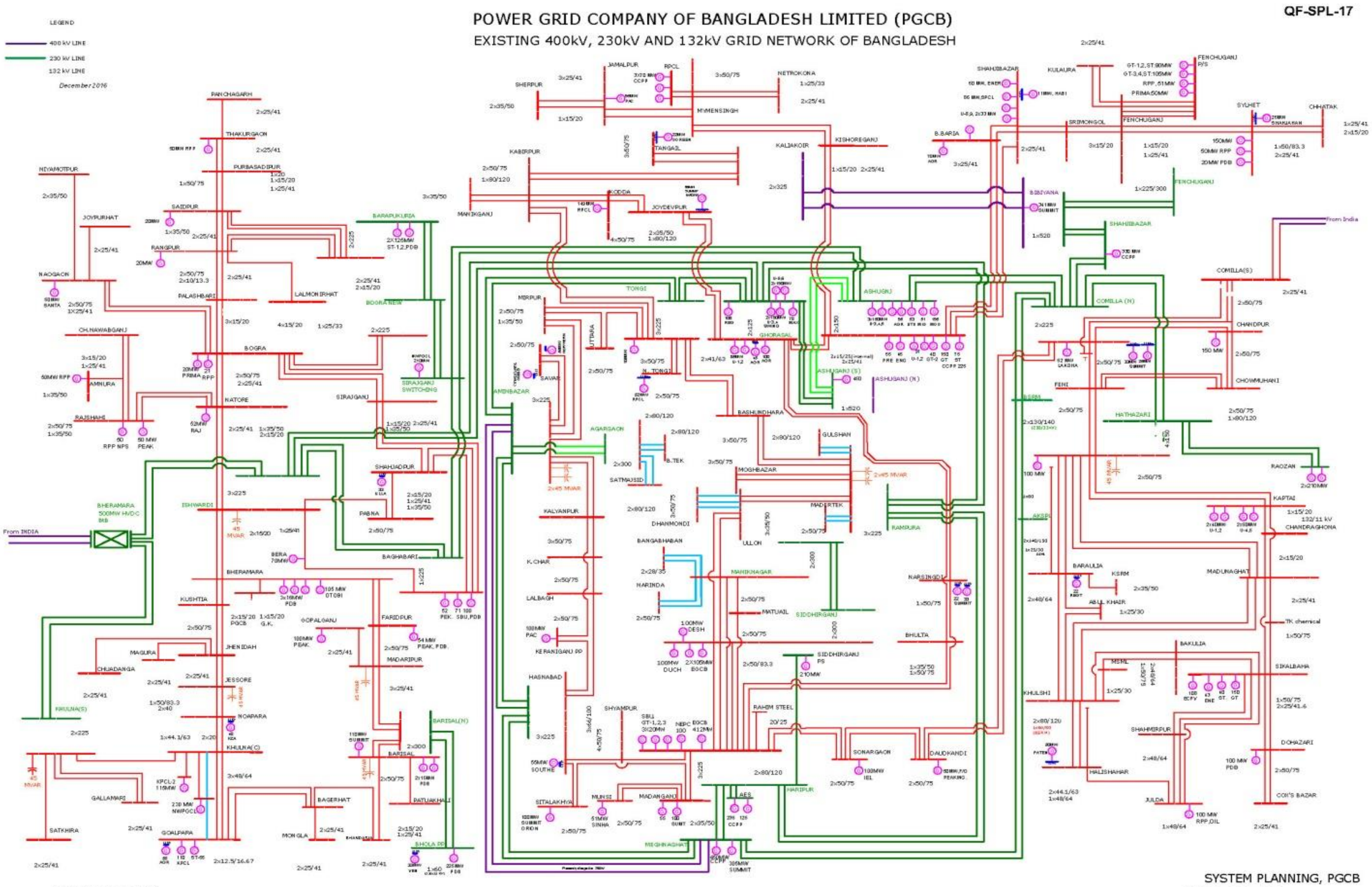
As per EIA report Mirsarai Economic Zone-II of BEZA and Tender ICB no PGCB/230KV/MIRSAR-BSRM/SS of PGCB, "Mirsarai Economic Zone is a fully government owned economic zone with an area of approximately 7716 acres under Bangladesh Economic Zones Authority (BEZA). A memorandum of understanding (MoU) was signed between BEZA and PGCB for setting up and maintenance of a grid substation in Mirsarai Economic Zone. PGCB will establish a 230/132/33 kV Grid Substation with provision of extension up to 400 kV in the land provided by BEZA as per MoU. Distance of proposed 50

MW solar power plant site from PGCB grid substation under BEZA is around 9 km. PGCB has invited bid for "Design, Supply, Installation, Testing and Commissioning of 230/33kV GIS Substation at Mirsharai EZ" on 09 August,2017 which will be completed within 18 months from the effective date of contract"

Hence based on discussions and suggestion from PGCB, Mirsarai 230 kV GSS of PGCB Or BEZA substation of PGCB (under construction) can be an option for power evacuation for this RE project. For this feasibility assessment study we have considered Mirsarai 230 kV GSS, however further power evacuation option and arrangement depend on the detailed grid connectivity and stability study of PGCB and client’s decision.

Following figure shows the Bangladesh PGCB power grid map:

Figure 14: *Technical map of PGCB grid in Bangladesh*



Source: *PGCB*

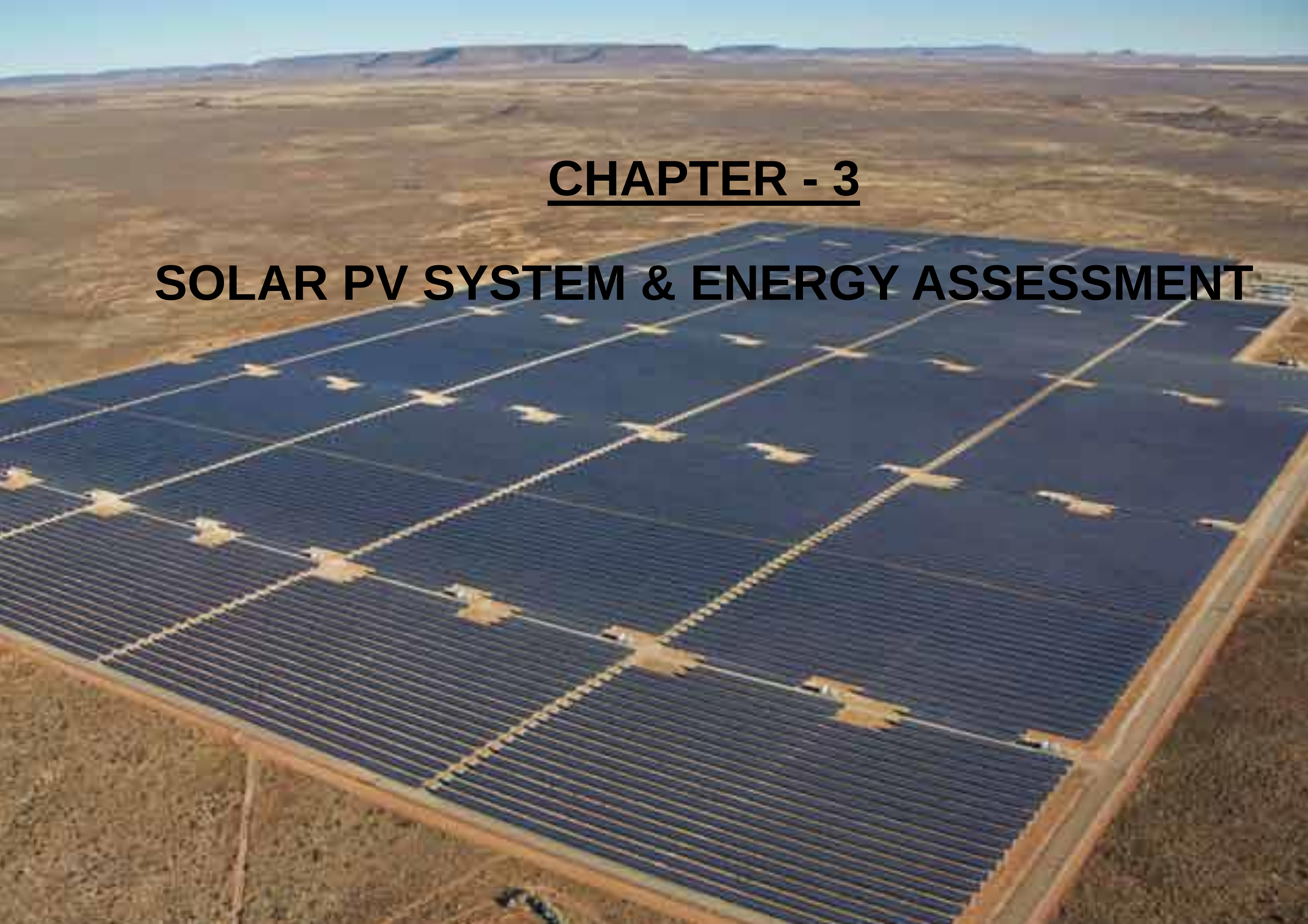
Followings are the images of the site captured during site visit:

Figure 15: *Project Site*

Source: *WFMS site visit*

CHAPTER - 3

SOLAR PV SYSTEM & ENERGY ASSESSMENT

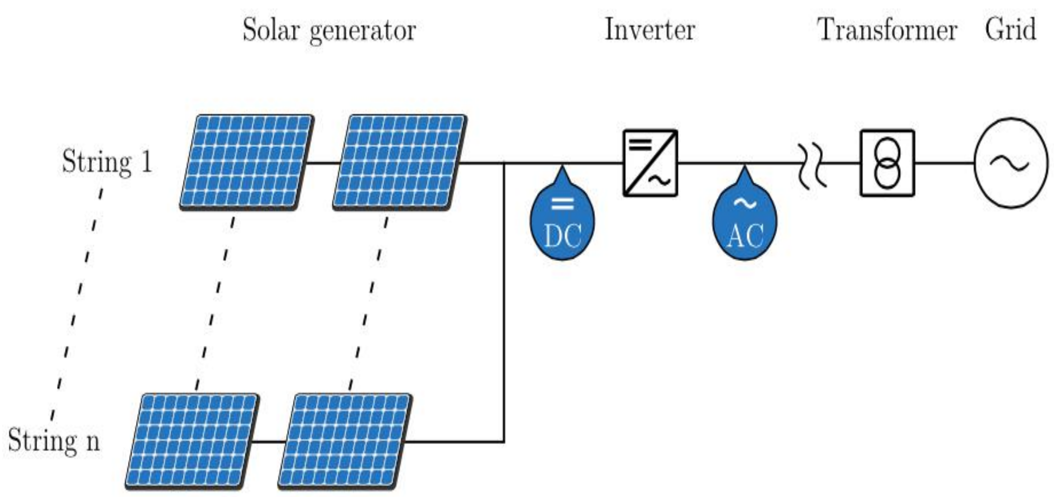


3.1 Basic of solar PV technology

Solar photovoltaic plants use Global Irradiation (GI), which is converted into electric energy in a solar generator. The solar generator consists of PV modules connected in series to form strings, which are connected in parallel and deliver DC power to the inverters. The inverter converts the DC power to AC power before transforming to the required voltage level allowing evacuation of power to the grid, as ilustrated in the figure below.

Figure 16: *General principle of a solar PV power system*

The components and layout of such plant are typically based on a 1000-volt system. This includes all components such as modules, cabling, combiner boxes, inverters, switchgears etc. In general, there is a tendency in the solar market towards 1500-Volt systems offering higher flexibility in terms of module interconnection, less cable losses, more simple installation and potentially lower specific equipment cost. However, for this project a 1000-volt system will be considered as the number of potential suppliers and experience with 1500-volt systems is still limited at the time of this study.



Source: *Suntrace GmbH*

3.2 Analysis of solar PV plant

The project specific boundary conditions have been assessed for the conceptual engineering and technology selection. Besides the market situation in Bangladesh, the technology has been analysed in terms of availability, inter-operability, reliability, scalability and maintenance aspects, suitability for the site, command and control systems, load consumption, system architecture, system output and performance. The main technologies analysed are:

- PV module technology (m-Si, p-Si and thin film)
- Mounting system (fixed vs. tracking)
- Inverter concept (central vs. string)

The site-specific boundary condition, in particular the risk of flooding, has been taken into account for the selected equipment and mounting system as described in the sections hereafter.

The analysis and comparison of various design options has been assessed for a **reference case** based on a **100 MW_{AC}** capacity.

3.2.1 Solar PV module

The main PV module technologies available in the market at commercial level were compared from a techno-economic point of view in order to find the technology that best fit the local ambient conditions found on the site. Three main technologies were evaluated:

- Polycrystalline modules (p-Si)
- Monocrystalline modules (m-Si)
- Thin film: CdTe, CIGS modules (TF)

Table 6: *Comparison of different module technologies*

Module Technology	Advantage	Disadvantage
Polycrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • Low installation costs • Low production costs • Crystalline cells are not harmful to the environment. • Established global competitions and high number of tier 1 companies	• Lower efficiency in comparison to monocrystalline technology, due to lower purity of the cell material: 14-18% • Because of the lower efficiency, a larger surface is required to reach the same capacity. • Higher risk of cracks during transport or mounting in comparison to thin film technology.
Monocrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • High efficiencies typically within 15-20%	• The initial investment costs are higher compared to polycrystalline modules • Higher risk of cracks during transport or mounting in comparison to thin film technology
Thin film	• Homogenous appearance • Flexible, hence for use at different applications and surfaces • Less affected by high temperatures and shadowing	• Very few market players, only First Solar (CdTe modules) with a significant market share • CdTe modules use cadmium telluride as semiconductor layer. As Cadmium is a toxic metal, the recycling of the modules by the manufacturer has to be secured to avoid emissions to the environment at the end of the lifecycle. • Thin Film technologies have faced technical problems also in the last decade. A special accuracy is needed in the selection of the product.

The CIGS based thin film technology has been excluded from this analysis since it is still not considered as major technology with sufficient suppliers allowing competitive bidding.

From a cost point of view the average price per watt peak of the modules vary among the different technologies with p-Si modules being slightly cheaper than TF modules. The prices for p-Si tier 1 modules in the Indian market (which is used as reference market because of size and strength in comparison to the actually small market in Bangladesh), range from 32 to 36 $-cent/Wp and 35 to 40 $-cent/Wp for TF. The price for monocrystalline modules per watt peak is about 10%[7] higher compared to p-Si module technology.

Different module technologies have been analysed to identify the most suitable option. This analysis is based on the reference case with 100 MWac considering a fixed-tilt system and central inverter technology. The following module technologies have been assessed:

SPV technology	Manufacturer
Polycrystalline module technology	Canadian Solar CS6X-315P 315Wp
High efficiency thin film modules	First Solar (CdTe) FS-4117-2 118Wp
Monocrystalline module technology	Canadian Solar CS6X-320M 320Wp

The technical and financial results of the comparison as well as cost assumptions for the applied PV modules are summarised in the table below.

Table 7: *Variation of module technology for the reference case scenario*

Parameter	Unit	p-Si	m-Si	Thin film
Energy Yield	GWh/a	202.02	204.57	206.84
Total area	Ha	135	135	130
Plant capacity	MWac	100	100	100
Peak power	MWdc	136	138	136
Module cost	USD/kWp	320	357	350
CAPEX	M USD	144.76	151.08	148.58
OPEX	M USD	1.73	1.76	1.73

[7] Average international PV module price for m-Si and p-Si; Source: http://pv.energytrend.com/pricequotes.html

Parameter	Unit	p-Si	m-Si	Thin film
LCOE *	USD cents/kWhr	9.36	9.60	9.34

***Concessional finance conditions**

The results indicate that, the higher efficiency of Monocrystalline modules cannot compensate the additional cost compare to the p-Si module cost per watt peak. The area required for the m-Si module configuration remains the same as for the p-Si, whereas the DC capacity is higher due to the higher efficiency of the modules compare to p-Si.

A high efficiency of First Solar’s CdTe modules has been considered for this analysis and the comparison shows that this module requires less area compare to other modules. The resulting LCOE for CdTe module technology is of similar magnitude compared to the p-Si technology. However, the higher technology risk of thin film module technology and the limited number of suppliers has to be taken into account.

Conclusion

With respect to the discussion above, the polycrystalline module technology stands as the best alternative from a techno-economic point of view. During the tendering stage, however, the selection of the module technology should be left open to bidders. Official approvals from manufacturers for the installation of their products on the specific site with its challenging features (proximity to sea, high wind loads) are needed. A particular attention should also be paid to the hail tests of the manufacturers.

Selected Technology

For the feasibility study, polycrystalline modules from Canadian Solar with 315 Watt peak and the model number CS6X-315P have been applied reflecting state of the art module technology. The technical characteristics of the chosen modules are given in the table below.

Table 8: *Characteristics of CS6X-315P PV modules*

Description	Value
Technology	Polycrystalline
Power output	315 W
Optimum operating voltage (@ STC conditions)	36.6 V

Description	Value
Current at Pmax (@STC conditions)	8.61 A
Open-Circuit Voltage	45.1 V
Short-Circuit Current	9.18 A
Temperature coefficient of Pmax	-0.41%/°C
Temperature coefficient of Voc	-0.31%/°C
Temperature coefficient of Isc	-0.053%/°C
Maximum System Voltage (DC)	1000 V (IEC) or 1000 V (UL)
Module efficiency; no. of cells	16.42%; 72
Power Tolerance	0 ~ + 5 W
Length	1954 mm
Width	982 mm
Height	40 mm
Weight	22 kg

3.2.2 Mounting Structure

Besides the project specific boundary conditions, the electricity production, required land usage, EPC costs, O&M costs and material liability must be analysed during the selection of the optimal mounting structure for utility scale solar PV plants. The market situation in Bangladesh and the availability of skilled labour force in the region of the site during construction and operation of the plant has to be taken into account.

The Consultant has analysed the following mounting structures:

- Fixed-tilt system
- Single axis tracked system

Fixed structures in the northern hemisphere are generally tilted towards the south with an inclination between 10° and 25° for the latitude of the project site. The fixed position of the modules leads to a generation curve with a peak at midday on cloudless days.

For tracker solutions, the aim is to follow the sun and maintain the panels perpendicular to the axis of incidence of the sun. Thus a greater efficiency in converting solar energy into electricity can be achieved. A single axis tracked system typically tracks the sun's position from East to West while being mounted along a North to South axis.

Advantages of tracking systems:

In general, the tracking systems can harness more energy, making them an attractive alternative in areas of high solar irradiation. Tracking systems are able to keep shading to a minimum but typically it requires more space for the same power output as compared to a fixed-tilt system. One of the most important aspects of tracking systems is the increased energy yield during the morning and evening hours, which helps to deliver a more constant electricity supply.

Disadvantages of tracking systems:

Tracking systems are more susceptible to failure, due to the number of moving parts and therefore, it also require more maintenance and maintenance costs can be around 15% higher. Trackers are more susceptible to high wind loads and in areas of high wind speeds the limited warranty for tracker systems may be reduced.

Comparison of fixed-tilt system versus single axis tracked systems

The decision to choose the type of mounting structure is typically based on a techno-economic evaluation. Extra energy generation must be assessed in comparison to the energy price and to the investment required. For the project site, the reference fixed-tilt system, as detailed in the sections below, has been compared against a single axis tracking system. A tracking angle towards East and West of ± 45° and a ground coverage ratio (GCR) of 40% has been assumed, reflecting the industry standard for projects of similar latitudes. The table width is 4 m with a pitch of 10 m and each tracker having a length of 150 m in total. The results are shown in the table below:

Table 9: *Comparison of fixed-tilt vs. single axis tracked system at DC/AC ratio of 1.36*

Parameter	Unit	Fixed-tilt	Single axis tracked
Plant capacity	MW_{AC}	100	100

Parameter	Unit	Fixed-tilt	Single axis tracked
Peak capacity	MW_{DC}	136	136
Energy Yield	GWh/a	202.02	222.88
Total area	Ha	135	227
CAPEX	M USD	144.76	154.82
OPEX	M USD	1.73	1.98
LCOE *	USD cents/kWhr	9.36	9.13

***Concessional finance conditions**

The above table shows that the single axis tracking system is having less cost in terms of LCOE compared to fixed-tilt system. The specific yield is about 10% higher while about 68% more space per MWac is required. Based on the analysis towards the selection of a mounting structure for the proposed project, the following needs to be considered:

- With respect to the project site being located next to the coast, the higher corrosion risk due to salty air needs to be taken into account in particular for any moving parts, such as the tracked mounting system.
- The fixed-tilt system offers simple construction and maintenance requirements, which favours for this project.
- The project represents the first utility scale PV plant of this scale in Bangladesh and the availability of experienced EPC and O&M companies in the local solar industry is limited.

Conclusion

As the project is to be the first utility scale PV plant in the market, a fixed-tilt system is proposed as the reference case takes into account the short field experience with trackers and complications posed by flooding at the site. The selection of the mounting system however can be left open to bidders during tendering stage, as single axis tracking systems are showing increasing adoption in recent years and potentially lower cost in terms of LCOE.

3.2.3 Inverter Technology

The inverter technology is crucial for the plant layout and equipment requirements such as string combiner boxes, DC and AC cabling, distribution transformers and others. Typically, a central inverter concept is applied for large-scale PV plants having several MW of capacity, while the string inverter concept offers more flexibility often required for smaller installations.

String inverter concept

The individual PV modules are connected in series to form strings. When using string inverters, the DC power from a few strings runs directly into a string inverter where it is converted to AC power. The string inverter is a small unit and can eventually be mounted underneath the PV mounting system. This concept offers higher modularity and flexibility of the system configuration compared to the central inverter concept and is typically applied for small PV plants and systems with different array angles and/or orientations. The nominal DC capacity of string inverters is typically below 100kW.

Central inverter concept

When using central inverters, the strings are connected in parallel through combiner boxes and they are then connected to the central inverter, which summarize typically between 500 kW to 2.5 MW of DC PV power. In utility scale PV plants, the PV field is generally divided into subfields, each of them served by an inverter of its own. This configuration is optimal for large systems where production is consistent across arrays. Moreover, the central inverter concept offers lower capacity specific costs and fewer component connections compared to the string inverter concept.

The selection of the inverter technology is based on the following considerations:

- The average price per watt peak of a central inverter is 8% lower compare to a string inverter. No major change in the price is expected for 2017 (GTM research, 2016).
- The central inverter concept requires less equipment and BOS activities compared to a string inverter concept. Turnkey systems available on the market also offer plug and play solutions combining for example inverters, MV transformers and switchgear in a single inverter station, which further minimises the BOS requirements.
- A large inverter capacity enables further cost reduction through economy of scale effects.
- In the Indian solar market (which is used as reference market because of size and strength in comparison to the actually small market in Bangladesh), there is a tendency towards high capacity central inverter systems for utility scale PV plants. The market is dominated by

European and Japanese suppliers such as ABB, TMEIC, Hitachi, SMA, Schneider TBEA, Delta, Sungrow, Gamesa Solar and Huawei (Khurana, 2016).

Conclusion

The use of large turnkey central inverter station is proposed in order to maximize the performance and reduce investment cost. Special coating and/or sophisticated ventilation and/or other protection measures of electrical components are likely to be necessary for various parts of the inverters and transformers. Additionally, official approvals from manufacturers for the installation of their products and required maintenance frequency during operation on the specific site with its challenging features (proximity to sea) are needed. The selection of the inverter however can be left open to bidders during tendering stage.

Selected Inverter

The suitability of the selected inverter regarding site-specific environmental protection requirements, such as the corrosion risk due to salty air, has been coordinated with the inverter manufacturer directly. The electrical components are designed in a way to withstand the salty air and a double coating of the MV transformer has been considered. The SMA inverter station MVPS-2000SC with 2,000 kWac capacity has been applied during the conceptual engineering reflecting state of the art inverter technology. The inverter station comprises of 2 x 1000 kWac SMA SC1000CP-XT outdoor inverters, the MV transformer, and MV switchgear. The output voltage of the inverter station is 33kV. The technical characteristics of the inverter are given in the table below.

Table 10: *Characteristics of SMA SC1000CP-XT inverter station*

Description	Value
Nominal AC output power	1000 kW
Max. AC output power (@25 °C)	1100 kW
Max. DC voltage	1000 V
MPP DC voltage range (@40 °C)	625 to 850 V
Max. DC current	1,635 A
Max. DC input power (@ cos φ=1)	1,122 kW
AC output voltage (station output)	33 kV

Description	Value
AC grid frequency	50 Hz./60 Hz.
Protection rating	IP54*
Ambient temperature range	-25 to +62 °C
Efficiency (CEC)	98.5%

**The protection rating of IP54 can be acceptable for the site depending on the inverter manufacturer. In any case, approval from manufacturers for installation of their products is needed and a lower protection rating should not be applied.*

The housing of the inverter station is based on a standard steel-framed 20-feet shipping container as shown in the figure below. The medium voltage transformer as well as protection and monitoring systems are embedded in the inverter station housing.

Figure 17: *Exemplary plant diagram for MVPS-2000SC inverter station*

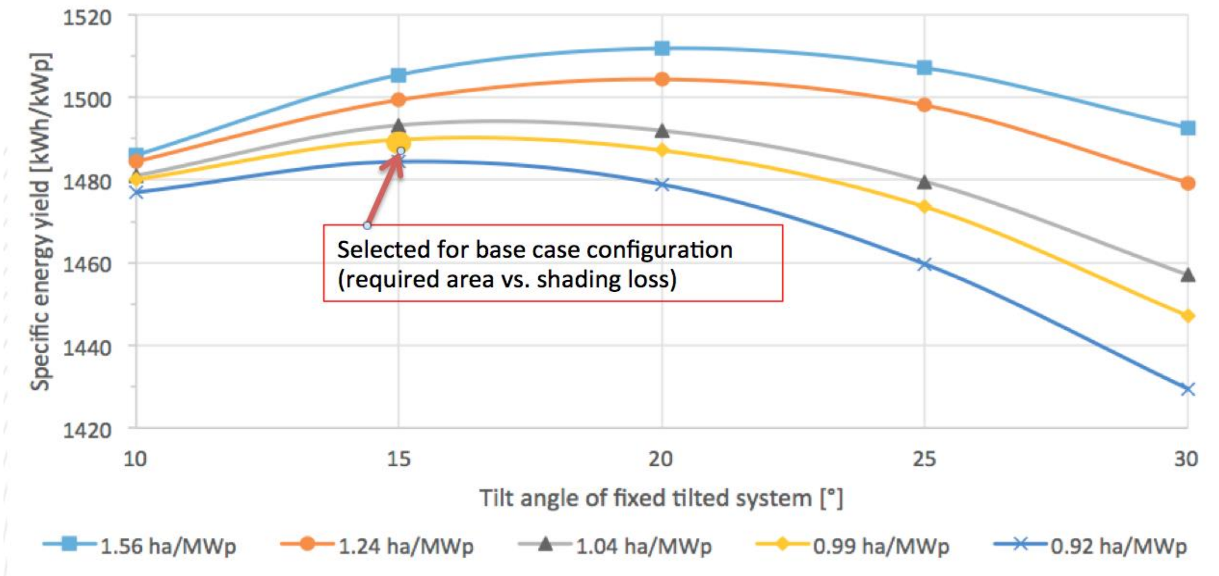
Source: *SMA*

3.2.4 Tilt angle and pitch optimisation

Module tilt angle decides the angle of incidence of solar radiation on the PV module to utilize maximum solar energy for generation of maximum possible energy. A PV module would produce more power with lower reflection and incident angle losses when the solar radiation is normal to its surface as compared to solar radiation incident at any other angle. The most optimum angle of tilt of PV modules at any given location depends on the latitude and the variation of solar irradiation over the year. Since each site has its own characteristics, it is necessary to determine the most optimum tilt for the site.

By increasing the tilt angle and keeping the pitch (distance between two consecutive rows of PV modules) constant, the shadow created by one row of PV modules on the next row of PV modules increases. This decreases the output of the PV power plant. Hence, it is also important to check the most optimum tilt angle for different values of pitch as shown in the figure below.

***Figure 18**: Annual energy yield respective to tilt angle and pitch*



***Source:** Simulation*

The above figure shows the specific energy yield of the fixed-tilt system for a tilt angle varying from 10° to 30°. The pitch has been varied from 8.3 m, 8.9 m, 9.4 m, 11.2 m and 14 m representing a ground coverage ratio (GCR) of 70%, 65%, 60%, 50%, and 40% respectively. The specific land use decreases by reducing the distance between the rows from 1.56 ha/MWp for 14 m to 0.92 ha/MWp for 8.3 m.. For each calculation a 3D shading scene has been modelled in PVsyst software to calculate the shading losses and annual energy yield.

Conclusion

To account for an efficient land utilisation, a specific land use of 1ha/MWp has been selected for the fixed-tilt system resulting in a tilt angle of 15° and a pitch of 8.9 m (GCR 65%). The resulting shading loss is below 2% compared to the case with 1.56 ha/MWp land use (GCR 40%).

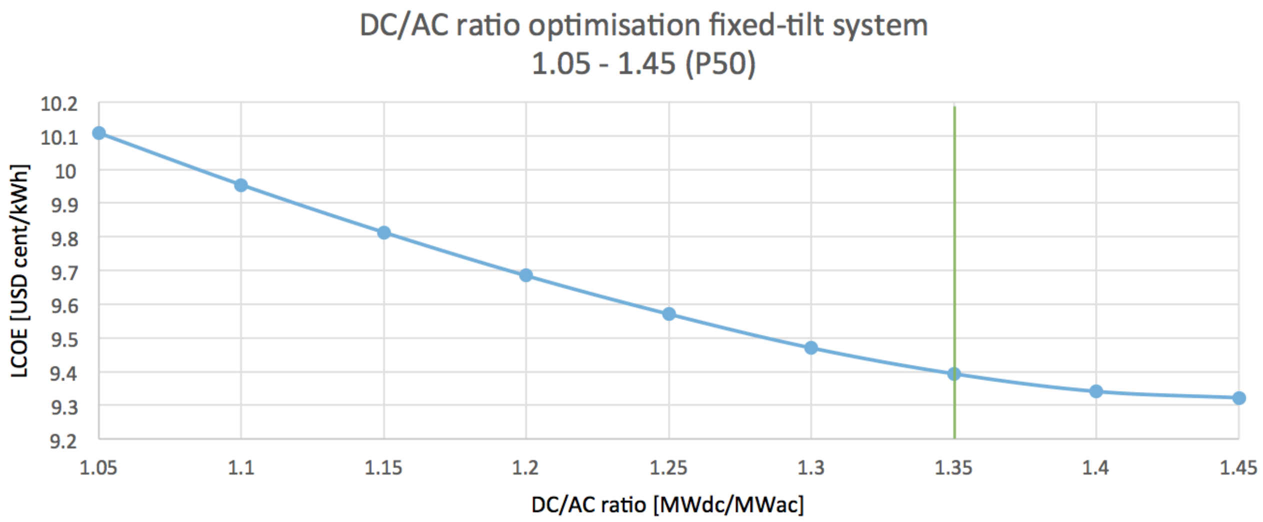
3.2.5 DC / AC ratio for optimal plant configuration

The type of PV module technology, type of inverter, the optimum tilt angle and the pitch have been determined for this study. The next step is to determine the DC/AC ratio for the optimal plant configuration. The DC/AC ratio is the ratio between the installed module capacity and the installed inverter capacity.

A change in the DC/AC ratio means, not only a change in CAPEX, but also OPEX. Hence, the LCOE is applied to determine the most optimum DC/AC ratio for the proposed solar PV power plant. The LCOE considers the complete cash flow including CAPEX, OPEX and also the financing conditions, and hence it is an ideal metrics to be considered. The LCOE is calculated using a financial model, the details of which are given in financing chapter of this report. The financial calculations are targeting an equity IRR of 10%. The CAPEX, OPEX and the annual energy produced are the main inputs; those can be varied in the financial model for simulating cases with different DC/AC ratios. The solar PV power plant configuration with the lowest value of LCOE is considered to be the most optimum.

The electricity production of the power plant has been calculated by varying the DC/AC ratio from 1.05 to 1.45 with an ascending interval of 0.5 considering optimum tilt angle of 15° and a pitch of 8.9 m. For each case the respective LCOE has been calculated and the results are shown in the table below. It should be noted that the energy yield calculation for the DC/AC optimisation is based on the reference case with 100 MW_{AC} capacity assuming concessional financing conditions.

Figure 19: *DC/AC ratio optimization for fixed-tilt system*



Source: *Simulation*

From this analysis it can be seen that by increasing the DC/AC ratio, the energy produced by the solar PV power plant increases as more number of modules are installed for the same AC capacity of the inverters (with consideration of inverter losses). It can be seen that lowest LCOEs can be reached for DC/AC ratios above 1.35 with only marginal differences if increased further to 1.4 or 1.45. DC/AC ratios greater than 1.45 are not feasible due to technical limitations of the inverters (maximum DC input power).

Even though it is technically feasible, it should be noted that inverter suppliers typically provide a figure for the maximum allowed DC input power within their data sheet of the respective inverter. In order to avoid warranty problems, it is recommended to get a final approval from the inverter manufacturer for the specific site and design.

Conclusion

For technical reasons, a **reference case** with a DC/AC ratio of **1.36** has been selected as optimal plant configuration. It should be noted that during tendering stage, bidders should assess the optimal DC/AC ratio for the presented technical concept in compliance with the minimum requirements.

3.2.6 Economies of Scale

The economies of scale have been analysed based on the reference plant configuration to evaluate suitable capacities for the pilot plant ranging from 10 MW_{AC} to the maximum capacity of 260 MW_{AC} that could theoretically be installed on site assuming complete land utilization for solar PV power generation. The results are shown in the table below.

Table 11: *Analysis of economies of scale based on the reference plant configuration*

Parameter	Unit	260MWac	100 MWac	50 MWac	30 MWac	10 MWac
Energy Yield	GWh/a	525.25	202.02	101.01	60.61	20.20
Total area	Ha	351	135	67	40	14
CAPEX	M USD	308.26	144.76	80.42	60.16	35.05
OPEX	M USD	4.23	1.73	0.95	0.63	0.23
LCOE*	$ cent/kWh	7.70	9.36	10.58	13.20	23.14

***Concessional financing conditions**

With lower capacities the quantity of equipment to be purchased by the EPC decreases which in turn increases the specific cost due to economies of scale. The specific infrastructural cost including power evacuation and site access as well as project development cost is considerable higher per MWp for capacities below 50 MW_{AC}. Moreover, tenders for small utility scale projects, especially in emerging markets, are less attractive for international players to participate, which in turn leads to less competitive bids.

Conclusion

The table above shows that due to the economies of scale the LCOE increases with decreasing system capacities. A capacity of at least 50 MW_{AC} is recommend for the pilot plant also getting international players into bidding.

3.2.7 DC Cabling

The study assessed the requirements of DC cable and as per this assessment the plant will have PV modules connected in series creating strings of 20 modules each. Since a large number of strings are needed, one junction level is defined using combiner boxes to group the strings and protect them with fuses. This minimizes material and installation costs associated with DC cabling and comply with the available DC inputs in the inverter. One combiner box has 24 input circuits (strings) which reduce the DC cables input to each inverter to 9. Thus, in total there are 18 combiner boxes per inverter station.

3.2.8 Monitoring and Control Equipment

Solar PV plant should be equipped with an adequate SCADA system. The SCADA system needs a reliable communication design to monitor and fully control the plant as required by the grid code. The SCADA system enables to monitor and control the inverter stations and substation allowing the constant measuring of the system performance and the recording of important system parameters, such as current, voltage, frequency, real and reactive power generation and power factor of the generated electricity.

A remote and local monitoring system will be installed. The remote monitoring system will facilitate monitoring of the plant through an Internet connection. Also the solar PV plant will be monitored and controlled from the solar PV plant central control room located within the on-site control building. The control room will completely be equipped to allow for daily use as workstation. In order to obtain a high availability and reliability of the solar PV plant, an Uninterrupted Power Supply (UPS) system should be installed in the Control Room to provide power supply to the rest of equipment and preventing the loss of data in case of emergency.

In order to evaluate the performance of the solar PV plant it is very fundamental to integrate a meteorological station. The following parameters need to be measured and recorded:

- Radiation on the plane of the array
- Module temperature of the array

In assessing the performance of the solar PV plant there is a need of obtaining an accurate measurement of the specific array conditions because the ambient conditions may be different within the solar PV plant due to clouds and other weather events.

It is advisable that at least three meteorological measurement stations are installed inside the solar field in order to measure the specific local meteorological conditions, which may vary significantly inside the solar field.

The meteorological measurement stations will be consisted of (but not limited to this):

- Calibrated pyranometer to measure the global inclined and horizontal irradiance on the plane of the array (POA) with a targeted measurement uncertainty of 2% and fulfilling secondary standard according to ISO 9060 classification. The POA pyranometer values are used to determine the Performance Ratio (PR) and reference purposes.
- Reference cell to measure the global inclined and horizontal irradiance on the POA and cell temperature.
- Thermocouple to measure ambient temperature with measurement accuracy of ± 1 °C.
- Resistance thermometer e.g. Pt100, Pt1000 or equivalent, to measure the temperature of modules with measurement accuracy of ± 0.5 °C.
- Anemometer mounted on a mast to measure the wind speed at the site. The exact location and height of the mast will follow the recommendations from supplier of the mounting system.

3.2.9 Boundary wall and fencing

To protect from infiltration of animals and unauthorized persons inside the site area, the periphery of the Solar PV power plant has to be covered by prefabricated / modular concrete wall with elevated barbed wire fencing (concertina). Prefabricated / modular concrete boundary wall will be erected of height 1.8 m with elevated spiral type round barbed wire fencing with 150 mm spacing of 1 m height, total height of the boundary wall will be 2.8 m above finished ground level. Boundary wall’s bottom portion of 450 mm will be covered by random rubble or stone masonry to protect the intrusion of surface water from adjacent land. Galvanised Iron (GI) post or concrete post shall be provided at spacing not more than 3 m. Vertical bracings should also be provided at certain distances for overall stability of the fence. Proper arrangements should be done to block outside water. Grills on inlet and outlet of drainage or waterways should be given as per executing agency.

It is suggested that the CCTV scheme should be implemented at the plant area, which as follows:

- 24/7 simultaneous coverage of the boundary and entire field (leaving no blind spots at any point of time) will be ensured through the installed CCTV systems.

3.2.10 O&M

In order to achieve the high up time of the solar PV power plant it is very much necessary to carry out planned preventative maintenance cycles (PMC) of all the defined system parts. These PMC are planned over the periodic manner for specific cycle interval based on the individual equipments / components requirement.

Below major sections required Preventive Maintenance Activities (PMA):

- Solar modules and solar array area
- Solar module mounting structures
- SMB and cabling
- All the equipment in the control room – includes HT panel and inverters
- Battery bank
- Control room
- Transformers – power & station transformer

The energy output of the plant will be monitored using the remote data acquisition system connected to charge controller. Significant reduction in energy output will trigger specific maintenance requirements, such as charge controller servicing or module replacement. In addition to this, on-going maintenance of the plant may be required and typical activities are as described below:

Modules

Visual inspection and replacement of damaged modules will be required at regular intervals. Cleaning of the module glass surface during long dry periods must be considered.

If go for conventional module cleaning then following would be water requirement for module cleaning (based on similar sector experience):

Parameter	Value	Unit
Capacity (Option 7)	272160000	Watt
Number of Modules	864000	Number
Per module water required	1.5	liters per module
Module cleaning cycle	15	in every 15 days

Total water required per annum	31.5	million liters per year

Hence, 1.296 million litres of water storage facility is needed at site in this conventional module cleaning case.

The site is surrounded by the Feni River to the east and Dakatiya River to the west. Water for usage during civil construction phase and module cleaning can directly be pumped from the existing water bodies.

And / Or

Around the site, hand pumps are usually used to draw groundwater (as per land revenue and irrigation department officials of the local UNO). Since the water table is as high as 6 meters from the surface therefore setting up multiple shallow bore wells for module cleaning system can be done.

Water (water bodies and/or ground water bore wells) before use in module cleaning requires lab testing and as per that water treatment, if needed.

Water supply for construction and O&M is subject to detailed hydrology study and decision of the client as per regional scenario of the water.

Considering site location and salinity of the site being coastal area, automatic dry type robotic module cleaning can also be an option (for further details on robotic dry type cleaning system refer section 5.5 of this FSR).

Wiring and junction terminals

Visual inspection for corrosion, damage such as chafing, and damage by rodents and birds, and for overheating of cables and connections. This requires the skills of an electrical technician.

Array Junction Box (AJB)

AJB maintenance requires the skills of an electrical technician. It involves visual inspection, tightening leads and cleaning using a vacuum cleaner or brush.

Safety devices

Checking connections, functionality of fuses, isolators and circuit breakers, and for signs of overheating

Major O&M activities which effects the plant performance and must recommended to perform at proposed PPMC plant are:

a. Monitoring the performance of the power plant by data logging, monthly report preparation & reporting on performance of power plant
b. Maintenance of module – Periodic cleaning of all SPV modules, scheduled maintenance of charge controller. Attend to the emergency break down of the components.
c. Careful logging of operation data and periodically processing it to determine abnormal or slowly deteriorating conditions.
d. Regular routine schedule for maintenance work such as keeping equipment clean, cleaning of module, spare parts and inventory maintenance, proper modification of all spares.

Note: The O&M plan will be submitted and followed by the EPC/AMC contractor.

3.3 Reference case plant configuration

During the techno-economic optimization and technology selection described in the sections above, the concept design for the fixed-tilt system has been identified for the **reference case** based on a **100 MW_{AC}** plant capacity.

The technical parameters of the concept design of the reference case developed during the initial investigations. A summary of the main plant characteristics of reference case is provided in the table below.

Table 12: *Main characteristic of the fixed-tilt system for reference case*

Description	Reference case	Unit
Plant capacity	100	MW_{AC}
Peak capacity	136	MW_{DC}
Number of modules	432000	Number
Number of inverters	50	Number
Modules per string	20	Number
Number of strings	21600	Number
Strings per string combiner box	24	Number
Combiner boxes per inverter station	18	Number
Tilt angle	15	Degree
Distance between rows	8.9	Meter
Table width	6	Meter
Modules per table width (portrait orientation)	3	Number

3.4 Solar PV energy yield assessment of the site

The aim of this solar PV energy yield assessment is to estimate the possible annual electrical energy generation potential of the site within a given confidence interval. The assessment was done for 20 years lifetime of the solar PV power system, which provides the basis for calculating the revenues and the profitability of the project.

An energy yield assessment consists of three main steps:

1) Evaluation of site
    a) On-site inspection
    b) Meteorological site assessment

2) Calculation of solar PV system energy yield
    a) Technical concept, design and layout
    b) Simulation of energy yield

3) Evaluation of results and uncertainty
    a) Assessment of uncertainties, errors and possible deviations

3.4.1 Evaluation of site

On-site inspection shows that, the flat land is suitable for a solar PV installation and no shading objects in the near vicinity have been detected. A detailed geotechnical study with soil testing and Topographical survey of the site has been performed by the third party (appointed by the Consultant) and the same study has been used as basis for infrastructure designing and costing. More details regarding site assessment are described in Chapter 2.

Based on several sources of solar data, a typical meteorological year (TMY) has been created. This TMY has been used as input data to calculate the energy yield for one year (typical year).

This section summarizes the results of the initial solar energy potential analysis of the project site. An estimate of the expected long-term average Global Horizontal Irradiance (GHI), which is closely related to PV power plant energy yields, along with the corresponding uncertainty is given. Typical long-term monthly average values of GHI expected at this site are also given. Furthermore, a typical meteorological year P50, P75 and P90 have been created, which can be used for energy yield initial estimations.

Basic site information

Country	Site Code	Latitude [°N]	Longitude [°E]	Elevation [m]
Bangladesh	BDFE0	22.79	91.38	5

Best estimate: GHI

Best estimate GHI		Overall Uncertainty	
avg [W/m^2]	sum [kWh/m^2]	[%]	[W/m^2]
199	1741	3.9	7.7

The following findings are derived from the above data set:

- The best estimate for GHI is 199 W/m^2 equal to **1741** kWh/ m^{2}a or 4.77 kWh/ m^{2}d.
- The best estimate is determined by the long-term hourly data set from SG and the typical year hourly data set from MN7 as the only sources since the uncertainties of the other examined and evaluated sources is too high for this region.
- The variation of GHI from the lowest to the highest examined data source for this site ranges from 1695 kWh/ m^{2}a NASA-SSE, to 1825 kWh/ m^{2}a, DLR-ISIS.
- The overall uncertainty for the long-term best estimate is **3.9 %** (1 σ value).

The table and figure below provide an overview of the long-term GHI values from the different data sets together with their overall uncertainty in comparison to the best estimate. In the figure below the lower and upper ranges of this best estimate are based on the uncertainty estimate. The error bars represent the assumed uncertainty of the individual data sources.

Table 13: *Overview of the long-term GHI values from different data sets and the best estimate*

Parameter	Overall uncertainty		Long-term yearly GHI	
	[%]	[W/m^2]	Avg. [W/m2]	Sum [kWh/m^2]
SG*	5.0	9.9	196	1719

DLR_ISIS	20.0	41.7	208	1825
NASA_SSE	10.0	19.4	193	1695
CMSAF	6.1	12.7	207	1816
MN7*	6.0	12.2	202	1768
best estimate	3.9	7.7	199	1741

*** used for calculation of best estimate**

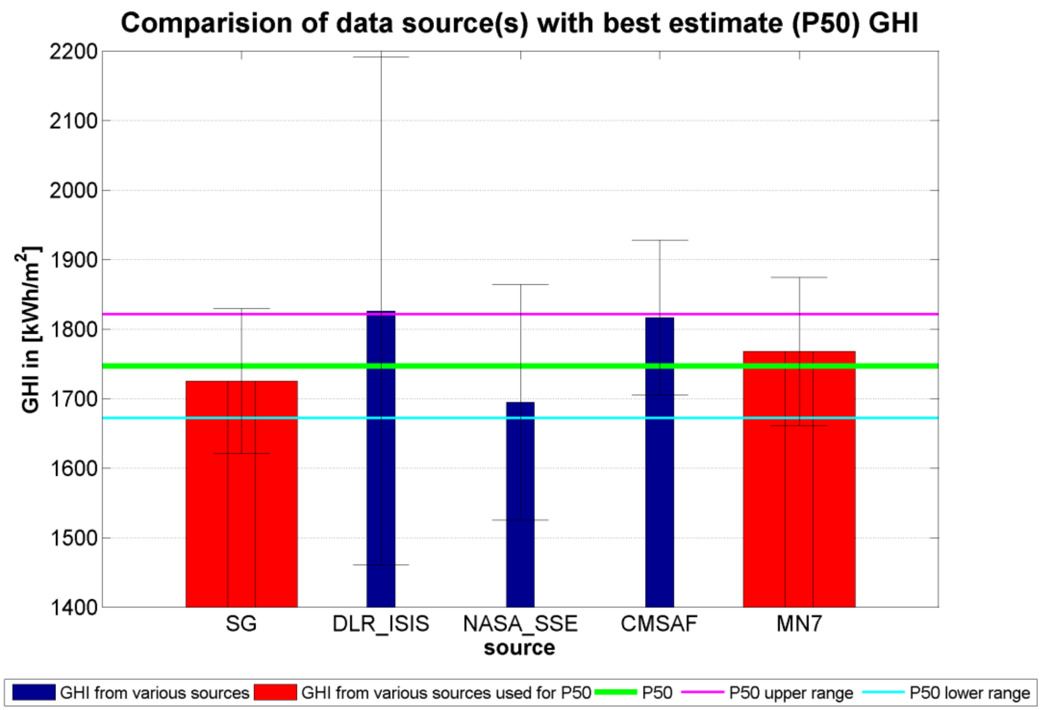
Methodology to calculate the best estimate

To determine the long-term best estimate of Global Horizontal Irradiance (GHI), a quality-weighted average as a combination of two independent data sets (Solargis long term satellite derived data in hourly time resolution & Meteonorm 7 TMY in hourly time resolution) is calculated based on Meyer et al. (2008)[8]. The resulting combined uncertainty of both data sets (Solargis: 5%, MN7: 6%) is also calculated using Meyer et al. (2008). The MN7 data set refers to a nearby measurement site, 74 km distant under similar conditions nearby the coast. By applying two completely independent data sets for determination of the P50 value, the overall uncertainty can be reduced to 3.9% (1 σ value).

Following figure shows the overview of the long-term GHI values from different data sets and the best estimate derived by a quality weighted average.

[8] Meyer et al., 'Combining Solar Irradiance Measurements And Various Satellite-Derived Products to A Site Specific Best Estimate', in *Proceedings of SolarPACES 2008* (presented at the SolarPACES 2008, Las Vegas, USA, 2008).

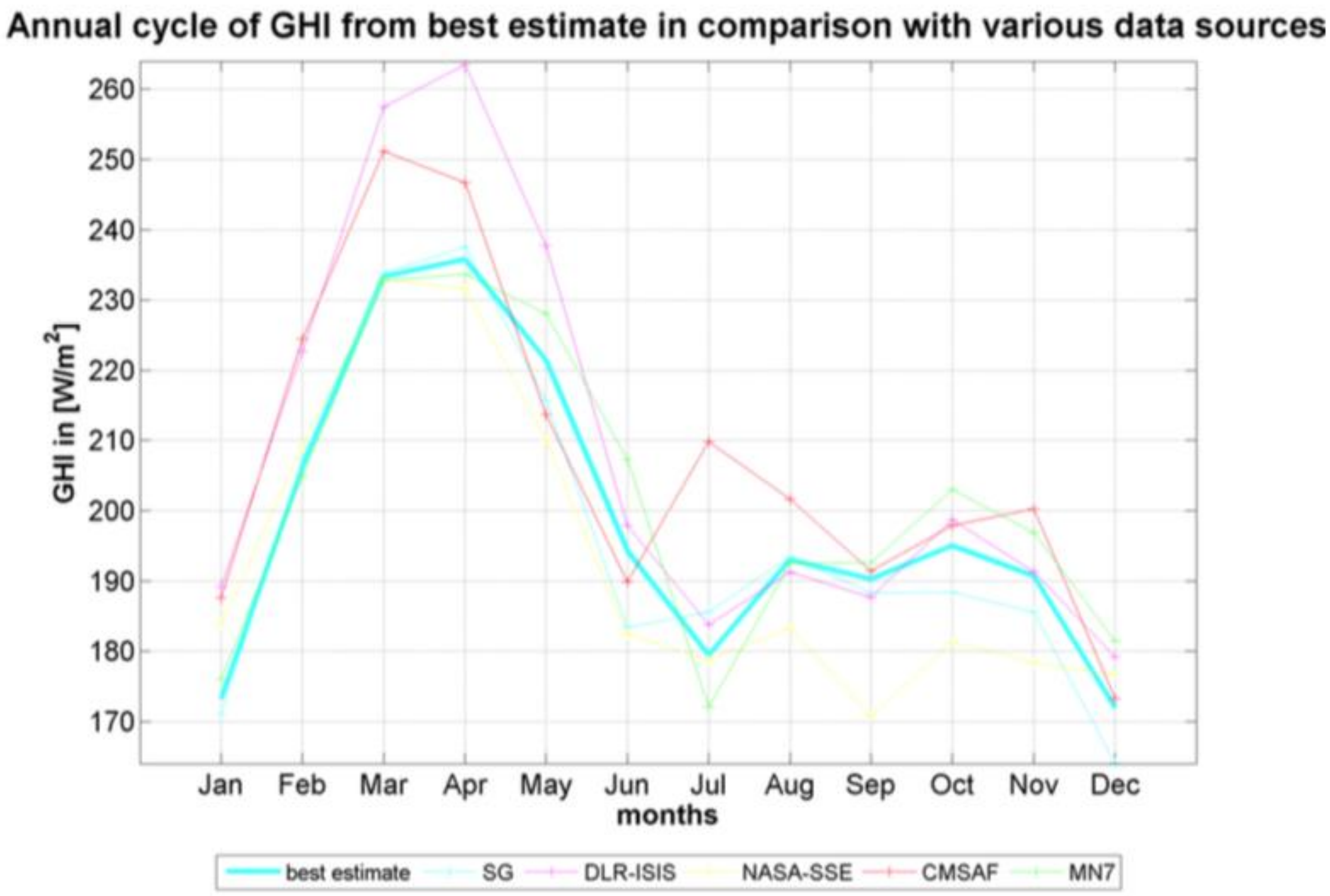
***Figure 20:** Comparison of data source(s) with best estimate GHI*



***Source:** Analysis*

The typical annual GHI cycle from different data sources is shown in the figure below. The variation in monthly means of GHI between different sources is not that large and lies within the normal deviation. As it can be seen, the annual cycle from the best estimate well represents the annual cycle of GHI from other sources. The monthly averages of GHI are given in the below figure and table.

Figure 21: *Annual cycle of GHI from best estimate in comparison with various different data sources*



Source: *Analysis*

Table 14: *Typical monthly averages of GHI [W/m²] from different data sources and best estimate*

Months	SG*	DLR-ISIS	NASA-SSE	CMSAF	MN7*	Best estimate
Jan	171	189	184	188	176	173
Feb	207	223	209	224	205	206
Mar	234	257	233	251	233	233
Apr	238	264	232	247	234	236
May	216	238	210	214	228	221
Jun	183	198	183	190	207	194
Jul	186	184	179	210	172	179
Aug	193	191	183	202	192	193
Sep	188	188	171	191	193	190
Oct	188	199	181	198	203	195
Nov	186	191	178	200	197	191
Dec	164	179	177	173	181	172
year avg.	196	208	193	207	202	199

*** used for calculation of best estimate**

Conclusion

The overall uncertainty for the long-term GHI best estimate is 3.9 % (1 σ value), which is rather low for the solar resource uncertainty. Further improvement of the data quality could be achieved by setting up a solar radiation measurement station at the site or in close vicinity. It should be in less than 10 km distance from the site and measurement campaigns should cover at least 12 months (one complete seasonal cycle). It is recommended to acquire time-overlapping data-series from satellites for correlation and perform an updated assessment of solar resource data. As long as no measurements nearby are available other measurements in the region are of help to lower uncertainty values. The complete solar resource assessment report is attached to this document.

Note:

- *Taking these results from the inter-comparison of on-site measurements against satellite derived GHI values from SG into account it can be concluded that the formerly determined long-term irradiation average (P50) for GHI of 199 W/m^2, or 1741 kWh/m^2 respectively, is realistic, since the SG-data set fits quite well the on-site measurements during the overlapping period.*
- *It should be noted that at least 12- months overlapping time period between on-site measurements and satellite-derived data are required to achieve high quality results. Using one complete year assures that all seasons are reflected. At the time of this study only six months of measured data were available for comparison.*
- *During tendering stage, the Bidders shall take into account on-site measurements for 12 consecutive months for correction of the satellite derived long-term data set. This will enable good characterization of local conditions and reduce the uncertainty of the long-term best estimate for GHI.*
- *For further details on "*comparison of satellite-derived GHI values to on-site measurement data" can be found in the separate data analysis and comparison report, that is with Appendix L and N.

3.4.2 Calculation of solar PV system energy yield

The main parameter considered for performance simulation of solar PV plant is the annual energy produced. The specifications of the reference case i.e. 100 MWac layout configuration is used for the energy yield assessment.

The simulation of the proposed project site with various technical concepts was realized using the software PVSyst version 6.43. The applied software is a state of the art tool that considers all relevant loss effects of a solar PV plant and is a widely accepted tool for the analysis of electricity yield of large-scale solar parks.

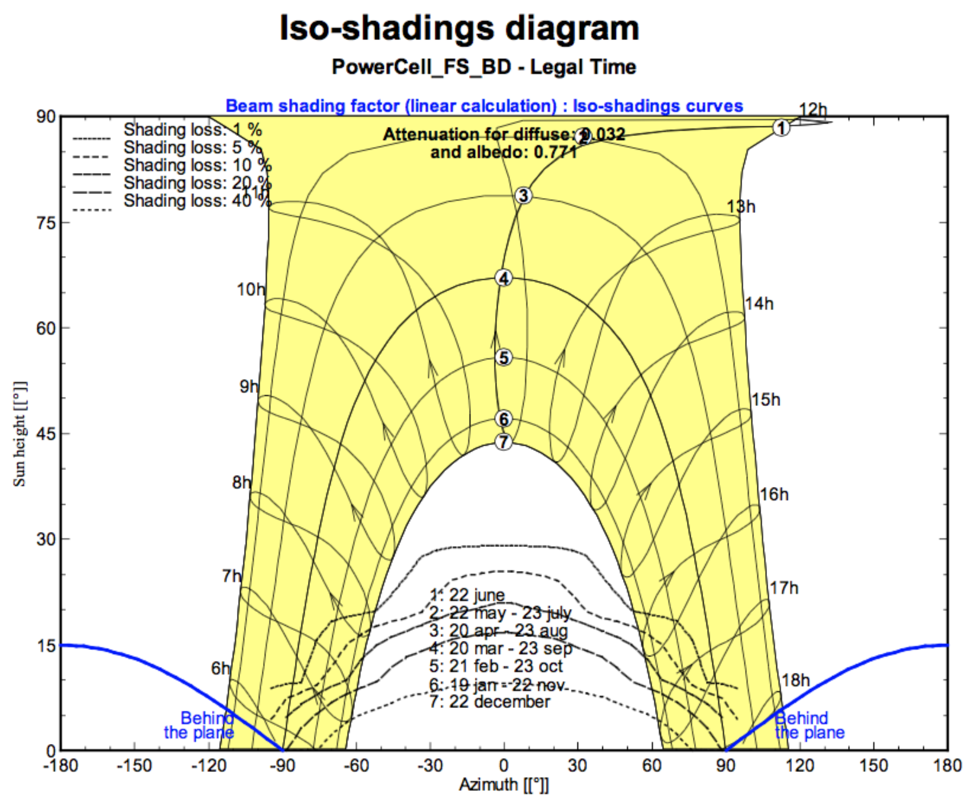
Solar PV power plant with fixed-tilt of 15°, pitch of 8.9m and DC/AC ratio of 1.36 (as mentioned in previous sections) has been considered for this assessment. With respect to the components of the solar PV power plant such as the type and quantity of modules, inverters, trackers, strings, etc. a model of the solar PV power plant is built in PVsyst software including a 3D shading scene of the PV tables for the purpose of simulation of the annual energy that can be produced from this solar PV power plant. A summary of the plant specifications is shown in the table 14 below.

Table 15: Summary of technical specifications for reference case

Parameter	Value
AC capacity	100 MW
DC capacity	136.08 MW
Inverters	Central Inverter stations: 50 x SMA inverter station MVPS-2000SC
Modules	Polycrystalline modules of 315 Wp Canadian Solar CS6X-315P; 432000 number of modules; 20 modules in series/string; 21600 strings in parallel
Mounting type	Fixed-tilt system with 15° tilt angle, 8.9m pitch (GCR 65%) and 6m table width
Area required	135 ha

3D Shading Scene

The shading scene is simulated internally in PVsyst and a shading factor is calculated for all the 8760 hours of the year. These shading factors are then used to determine the shading caused by one row of PV modules on the next row of PV modules, which are in turn used for simulating the energy produced. The resulting shading diagram is shown in the figure below.



System losses

Once the basic system components and the layout are defined, the next step is to define various losses those occur in the system. The following assumptions are used during the energy yield modelling process (as shown in the below table):

Table 16: Summary of energy losses for the reference case

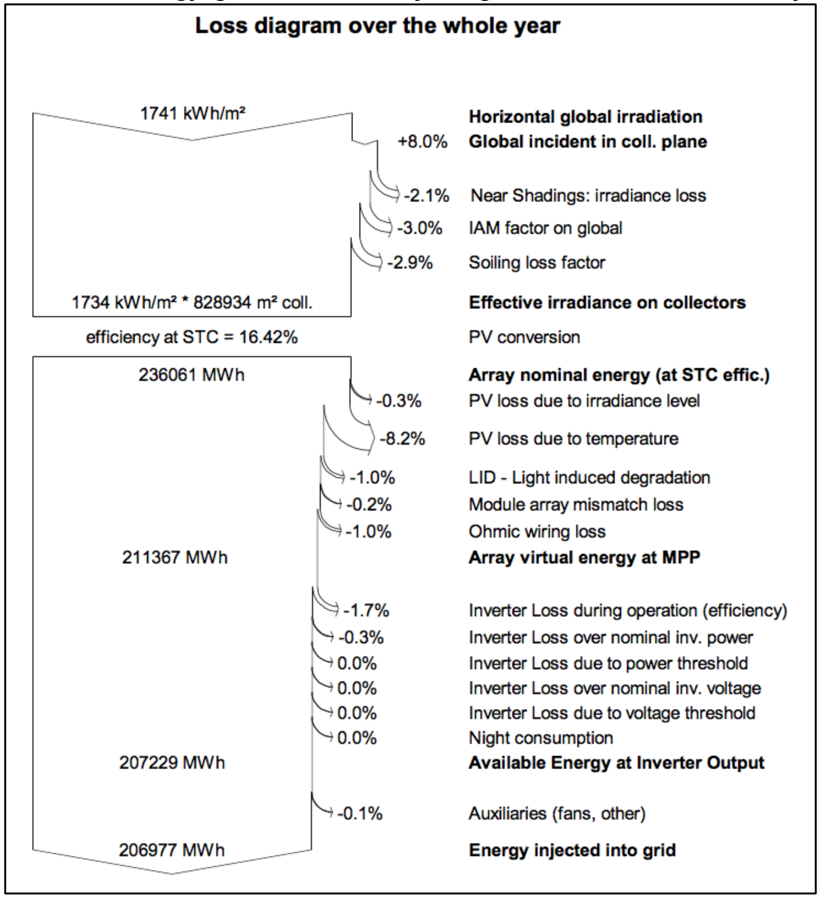
Energy loss	Value	Unit
Constant Temperature loss factor (Uc)	29	W/m^2K
DC Global wiring resistance (at STC)	1.5	%
Light Induced degradation	1	%
Module mismatch losses (at MPP)	0.2	%
Incident effect, ASHRAE parameterisation (IAM = 1 – bo (1/cos I – 1)	0.05	(bo)
AC wiring loss – inverter to injection point	=<2*	%
Soling losses	3	%
Auxiliary consumption (fans etc.)	60	kW
Availability	99	%
Annual degradation	0.5	%

*** The AC losses were calculated separately and have been considered during a post-processing step**

3.4.3 Evaluation of results and uncertainty

The PVsyst software calculates the energy produced for 8760 hours of the year by taking into consideration various losses mentioned above. A Sankey diagram (shown in the below figure) summarising the major energy losses those take place in the solar PV power plant.

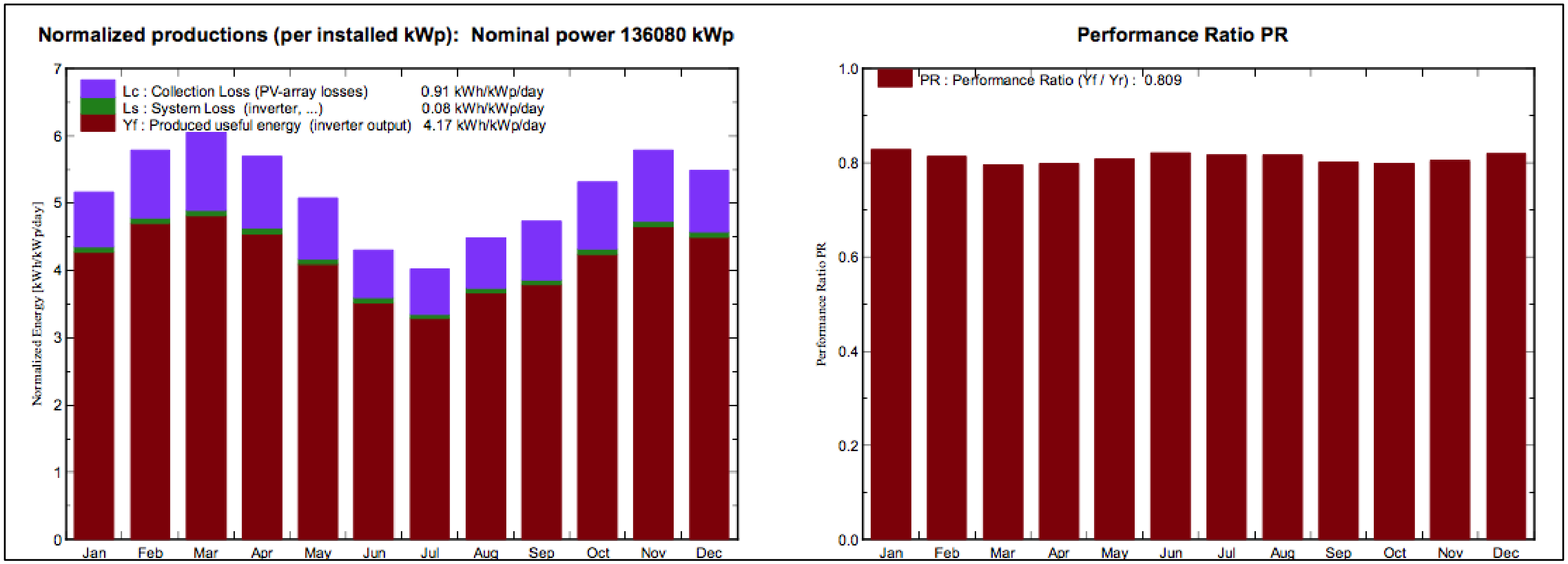
Figure 22: *Annual energy gain/loss sankey diagram obtained from PVsyst software*



Source: *PVsyst software simulation*

The monthly electricity generation indicated in the figure below shows a relative constant generation profile along the year with a maximum variation between months of 36%.

Figure 23: *Energy generation simulation results of 100 MW_{AC} solar PV reference case plants at Sonagazi*



Source: *PVsyst software simulation*

As per simulation study and analysis, the reference case with 100 MW_{AC} solar PV power project would produce ≈ **152.5 GWh/yr** including all losses at PLF of 17.41% with 81.32% performance ratio.

Uncertainty analysis

A statistical analysis of resource data, assessing the uncertainty in input values and limitations of the simulation software are applied to derive the appropriate levels of uncertainty in the final energy yield estimation. Several assumptions are made and models are used for this yield analysis, all these assumptions and models are subject to uncertainties. The following table 16 shows a summary of all relevant parameters and their uncertainty for the reference case.

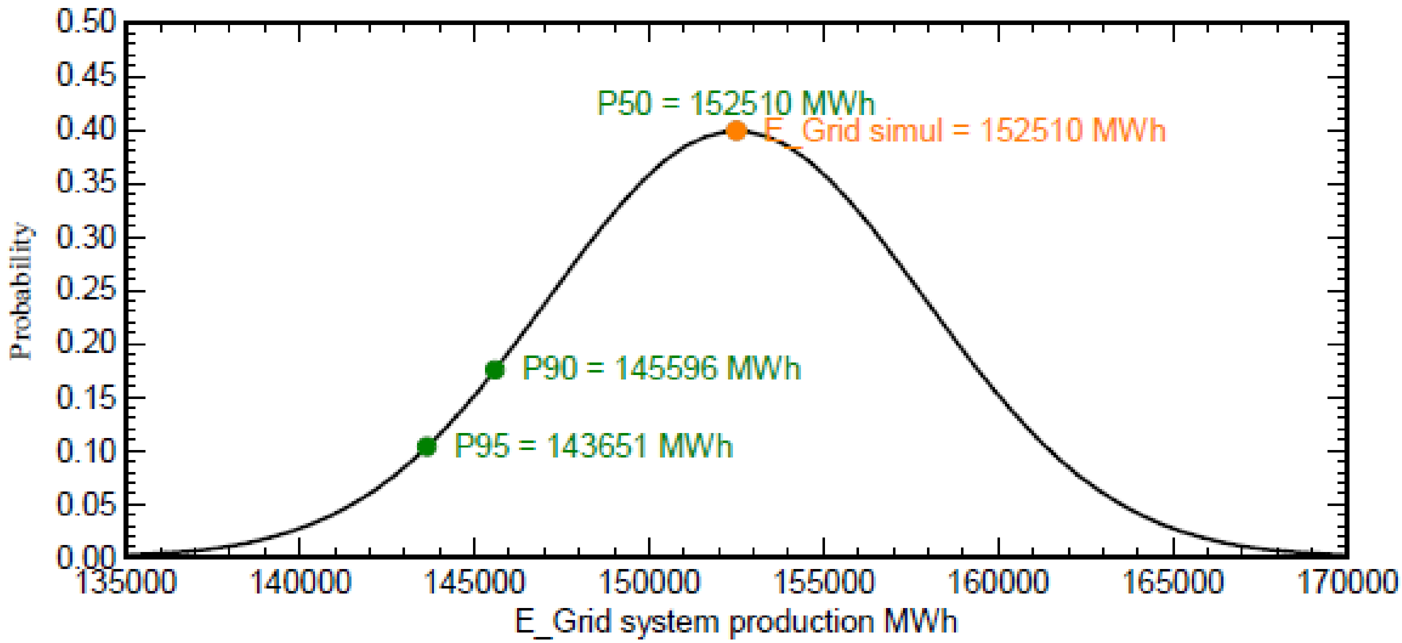
Table 17: *Summary of energy yield modelling uncertainties of reference case*

Simulation step or loss factor	Uncertainty
Horizontal Irradiation	4.3
Insolation on tilted Plane	1.5
Soiling	0.7
Nearby Shading	1.0
Horizon Shading	0.0
Reflection	0.7
Spectral Irradiance	0.7
Temperature	1.0
Mismatch	0.5
Module Quality	1.0
DC Cable Losses	0.1
Inverter	0.5
AC Cable Losses	0.1
Transformer	0.2
Overall Uncertainty*	**5.1**

*** The overall uncertainty is calculated as square root of the sum of the squares**

The probability distribution of the system production forecast mainly depends on the solar resource data applied for the simulation as the solar resource uncertainty is usually the highest for the energy yield estimation. Besides the solar resource uncertainty, the uncertainty for the simulation has to be taken into account, which are summarised in the above table. The resulting probability distribution for the reference case (showing the P50, P75, and P90 probability for the annual energy yield) is shown in the figure below (note that the energy yield shown is w/o AC losses as assessed during post-processing step)

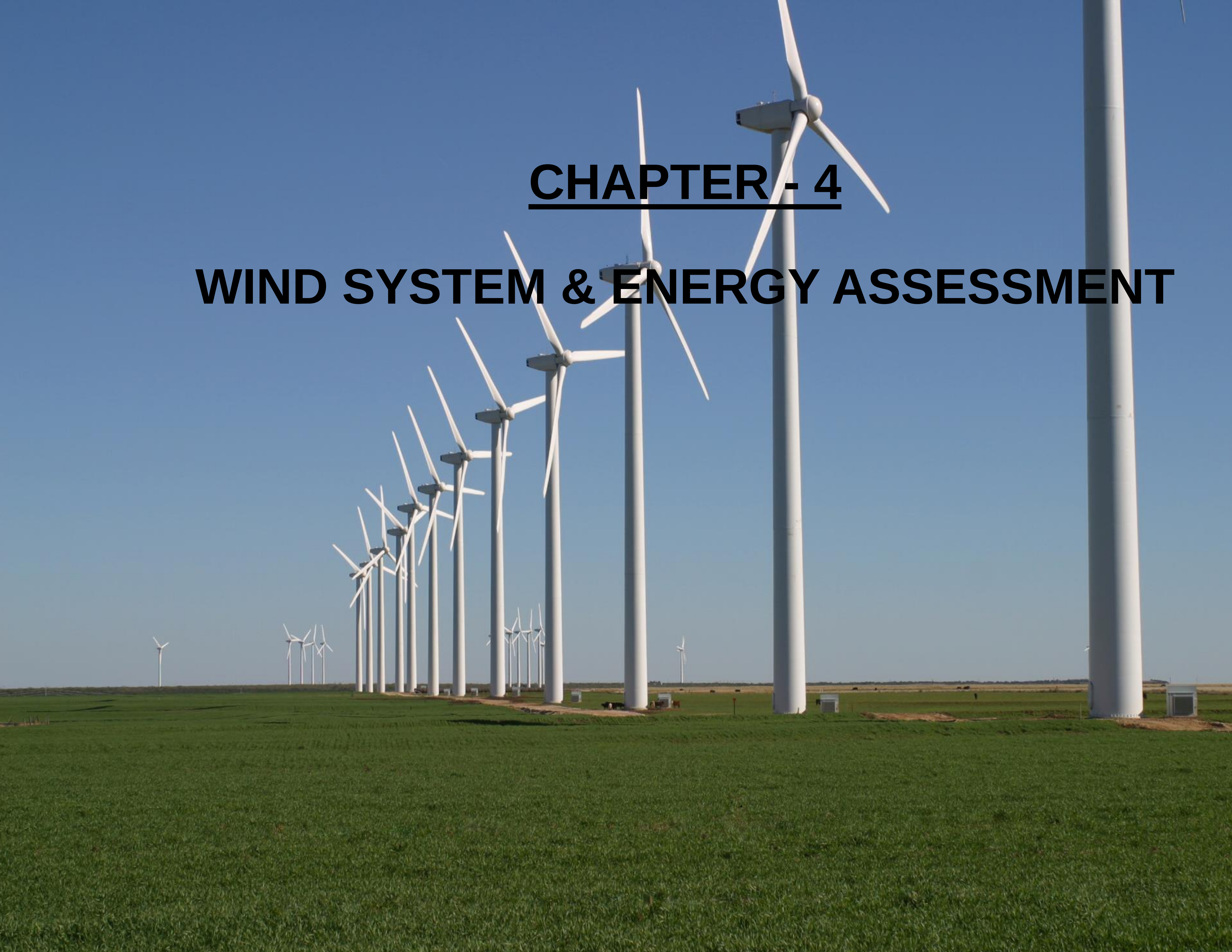
Figure 24: Probability distribution for the reference case showing



Source: *PVsyst software simulation*

CHAPTER - 4

WIND SYSTEM & ENERGY ASSESSMENT



This section illustrates about the typical wind resource seismic assessment carried out for the region of interest (RoI) using the processed open source data which is the long term reanalysis data sourced from various weather agencies available at several pressure levels and different spatial resolution. The data analysis and wind flow modelling has been carried out using globally accepted software models i.e. Windographer and Windfarmer and as per industry practises. The modelling has been carried out considering three best in class wind generators: Gamesa-G114-2.0MW, Vestas-V110-2.0MW, Suzlon-S111-2.1 MW placed optimally considering least wake loss within the RoI (explained in further sections).

Based on the wind flow modelling results, the gross and net annual energy estimates has been derived and presented in this report in the wind energy yield assessment section.

4.1 Basic of Wind Technology

Wind power is the conversion of wind energy into electricity or mechanical energy using wind turbines. The power in the wind is extracted by allowing it to blow past moving blades that exert torque on a rotor. The amount of power transferred is dependent on the rotor size and the wind speed.

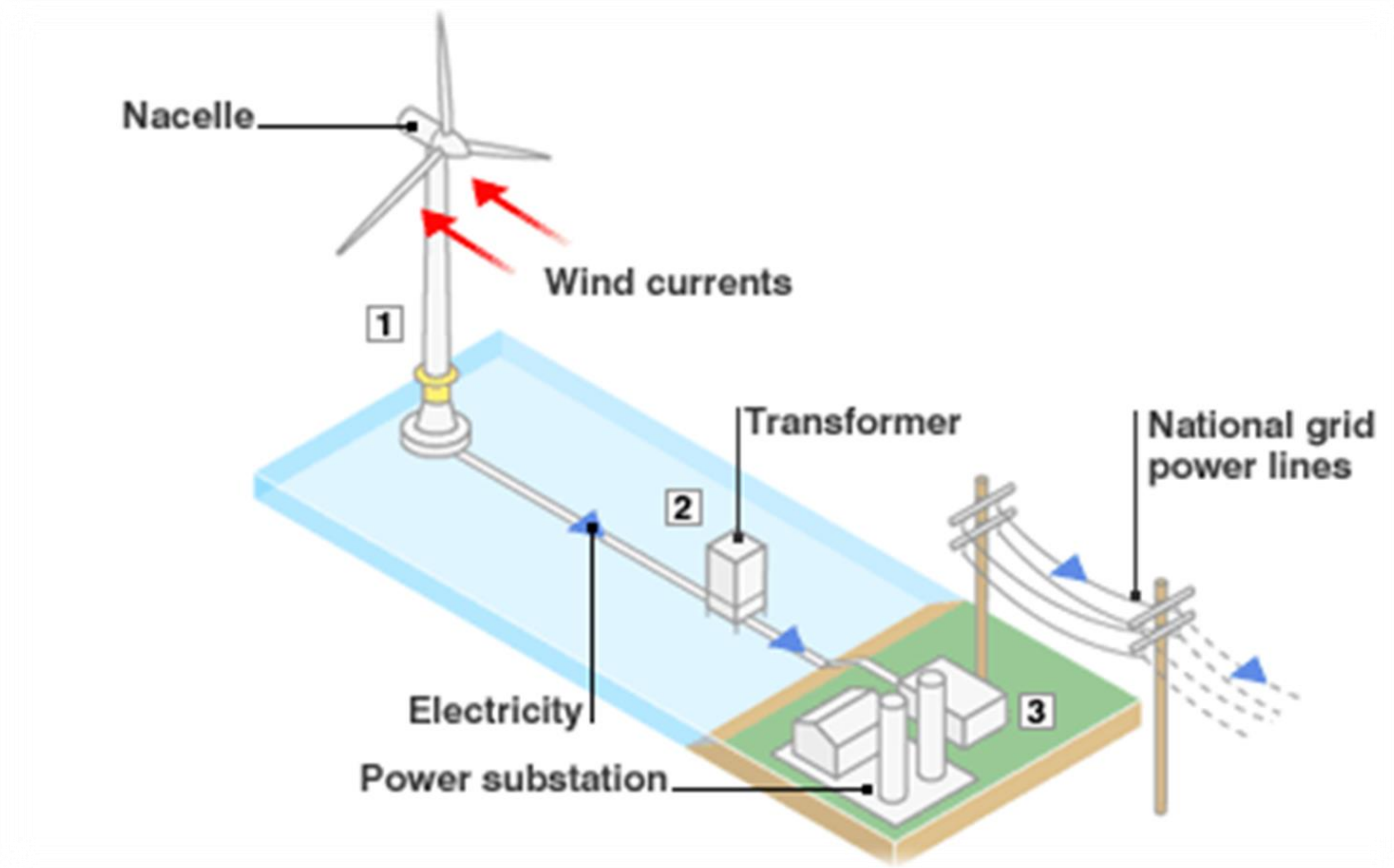
Wind turbines range from small four hundred watt generators for residential use to several megawatt machines for wind farms and offshore. The small ones have direct drive generators, direct current output, aeroelastic blades, and lifetime bearings and use a vane to point into the wind. While the larger ones generally have geared power trains, alternating current output, flaps and are actively pointed into the wind.

Direct drive generators and aeroelastic blades for large wind turbines are being researched and direct current generators are sometimes used.

Since wind speed is not constant, the annual energy production of a wind converter is dependent on the capacity factor. A well sited wind generator will have a capacity factor of about 35% (energypedia.info).

As a general rule, wind generators are practical where the average wind speed is 4.5 m/s or greater (energypedia.info). Usually sites are pre-selected on the basis of a wind atlas, and validated with on site wind measurements.

Figure 25: *Basic working principle of wind technology*



Source: *easywindenergy*

4.2 Technical Methodology and Concept

A Meso scale modelling and mapping of site wind resources for RoI has been carried out. The methodology in respect to conduct that modelling and mapping is illustrated below:

Figure 26: *Methodology followed for carrying out meso-scale modeling*

Task 1.1 – Examination of Primary and Secondary datasets	• Examination of satellite data • Procurement of other global datasets i.e. DEM, LULC etc
Task 1.2 – Processing of Global datasets	• Processing of Digital Elevation Model (DEM) • Procesisng of LandUse /LandCover • Processing of NCEP/NCAR datasets
Task 1.3 - Boundary Layer Wind Mapping Model (BLWMM)	• Run Boundary Layer Wind Mapping Model using primary and secondary datasets • Model validation and Minimization of error in estimation • Creation of Boundary Layer Wind Field
Task 1.4 – WinDForce Meso Map Assessment Model (WMMAM)	• Modeling/ Simulation • Long term wind speed computation at various heights over grid elements • Wind Speed map at 100 and 120 ma.g.l
Task 1.5 - Annual Yield Assessment Model (AYAM)	• Micrositing, optimal layout of the windfarm, and Capacity assesment, • Computation of annual yield from a G114. 2.0 MW and V110 2.0 MW Model
Task 1.6 – Physical site characterisitc and approriate locaiton for mast installation	• Shortlist approriate sites for mast installation • Evaulation of approriate sites with respect to complexity of terrains, vegetation, obstacles of wind flow etc through site visits • Selection of final point for installation of measurement mast in consultations with IFC

The methodology involves setting up a grid of 3 km resolution over RoI and the use of NCEP/NCAR and MERRA re-analysis data for computing long term means. Extrapolation of the computed wind speed at boundary layer using different spatial variables, interpolation of the extrapolated wind speeds to arrive at a mean annual wind field at boundary layer and then re-computation of wind speed at different respective hub heights. The analysis carried out is shown in below figure:

Figure 27: *Methodology flow chart for computing wind speed at different heights*

Following are points of data consideration for this modelling:

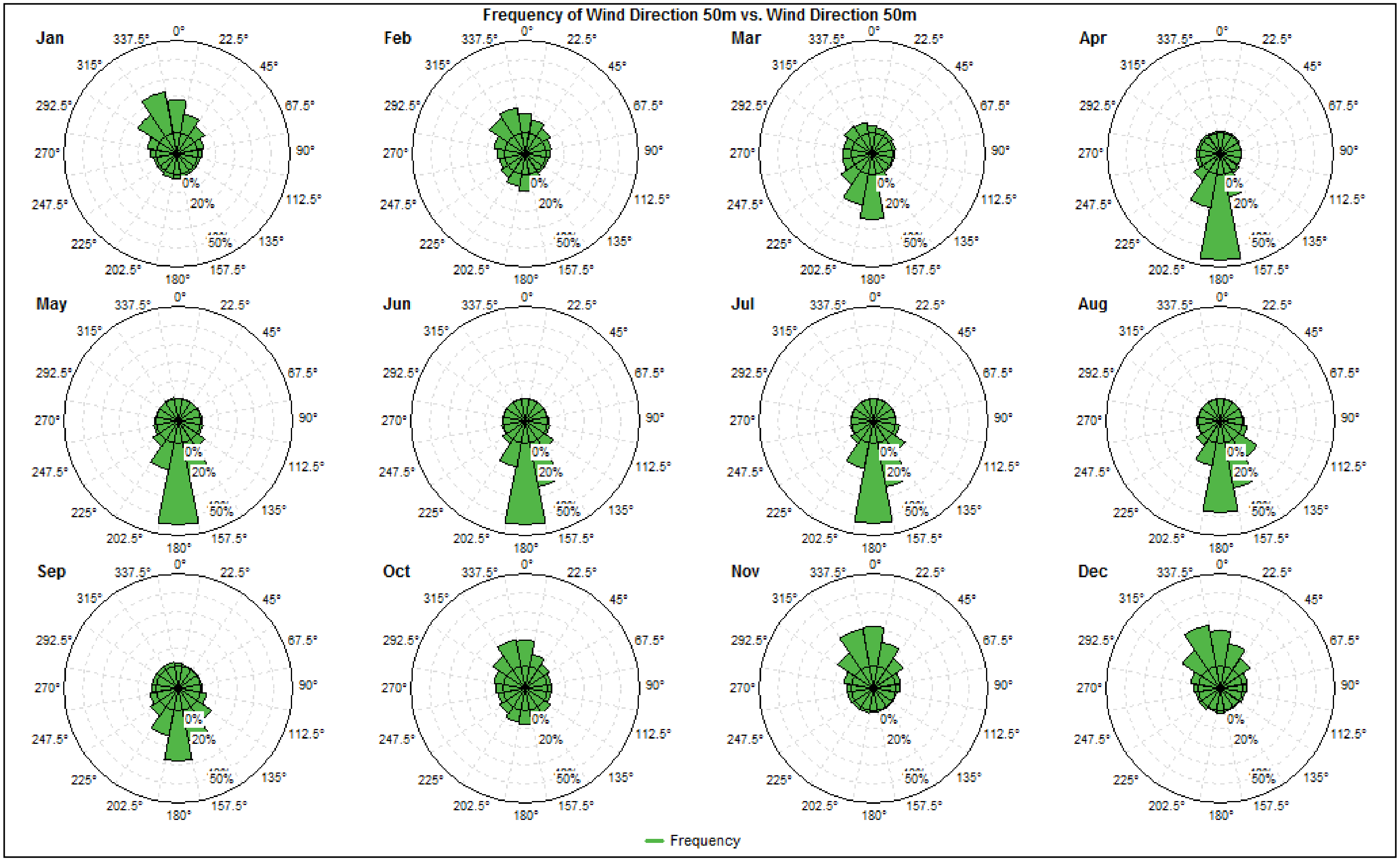
- The NCEP/NCAR reanalysis project monthly mean wind speed dataset was procured from the NOAA for the year 1948 to 2016. The datasets was available in .NC format which was further processed and a series of monthly values were generated. Long term mean was calculated for the all procured points to arrive at mean annual wind field at 10m height.

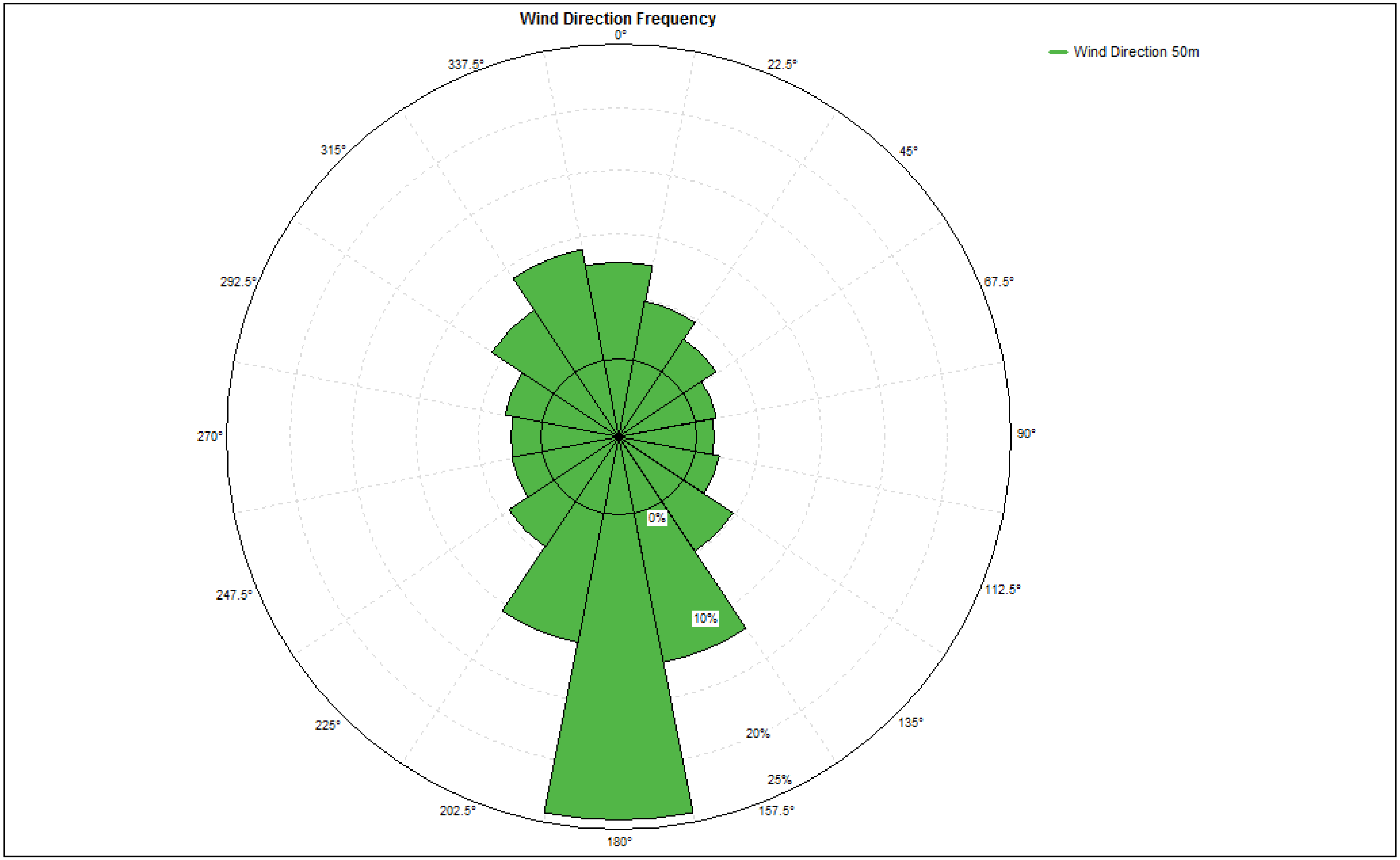
- The land use data was procured from the Global Land Cover 2000 Project (GLC 2000) for South East Asia and was extracted for the region of interest. Several random points were generated to validate the data with the observed Land Use category existing on the respective points. The validation was performed using some observed points procured during the early site visit to the country and others with the latest Google Earth Satellite imagery. It was found that Global Land Cover 2000 Project database was aligned with the observed Land Use categories.

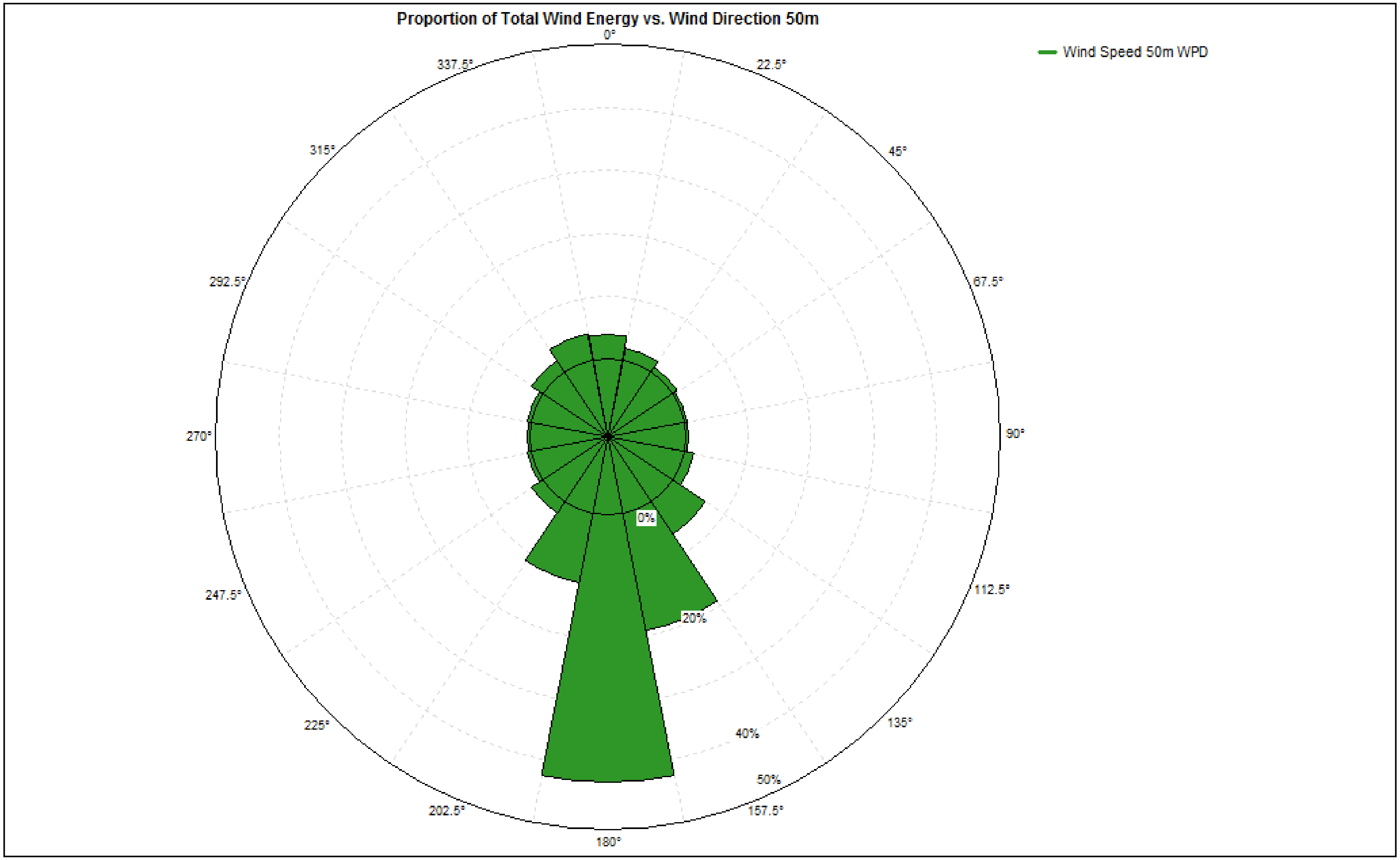
- The Advance Space borne Thermal Emissions and Reflection Radiometer (ASTER) digital elevation model (DEM) procured for the RoI was divided into several tiles of varying latitude and longitude which was further joined by mosaicing in ArcGIS 10.0. The sinks of raw digital elevation model was filled using fill in hydrology tool in Arc tool box, that results into a smooth elevation surface, where no values were originally found. The DEM extracted for the RoI is shown in the below figure.

Following figures show wind direction and frequency for the site:

Figure 28: *Wind direction and frequency*




Wind Direction Frequency
Wind Direction 50m
0°
22.5°
45°
67.5°
90°
112.5°
135°
157.5°
180°
202.5°
225°
247.5°
270°
292.5°
315°
337.5°
0%
10%
20%
25%


Proportion of Total Wind Energy vs. Wind Direction 50m
Wind Speed 50m WPD
0°
22.5°
45°
67.5°
90°
112.5°
135°
157.5°
180°
202.5°
225°
247.5°
270°
292.5°
315°
337.5°
0%
20%
40%
50%

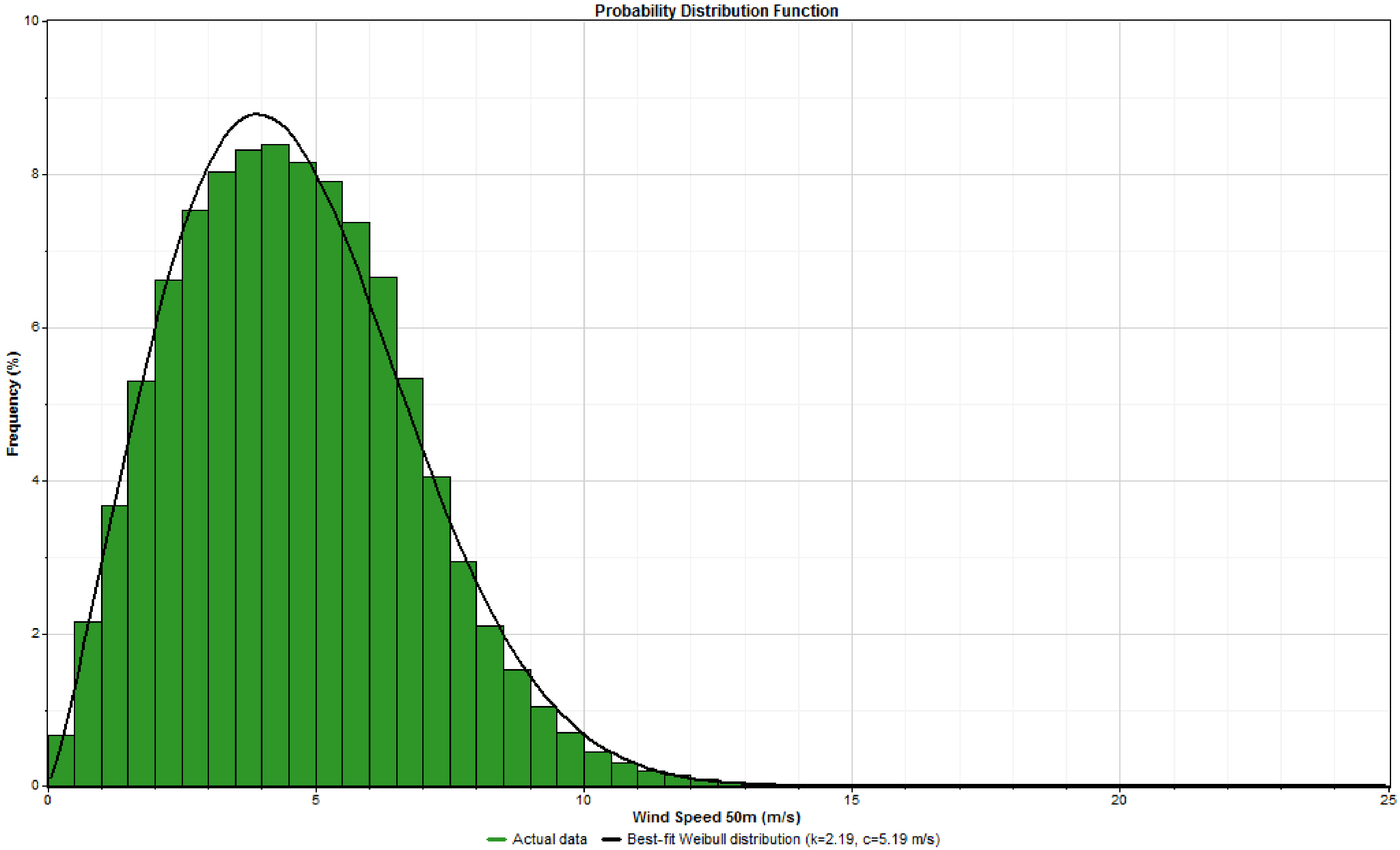
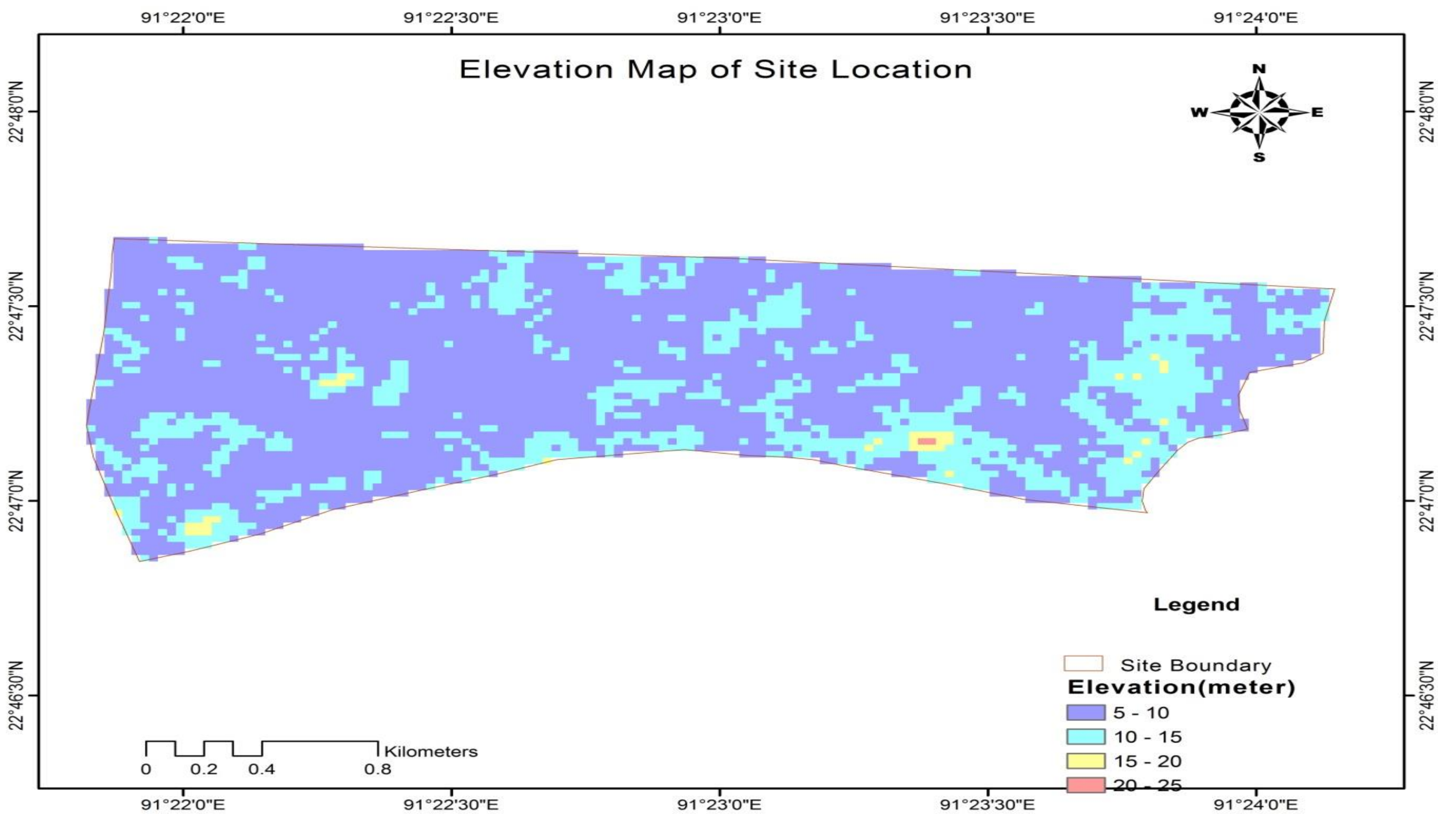

Probability Distribution Function
Frequency (%)
10
8
6
4
2
0
0
5
10
15
20
25
Wind Speed 50m (m/s)
Actual data
Best-fit Weibull distribution (k=2.19, c=5.19 m/s)

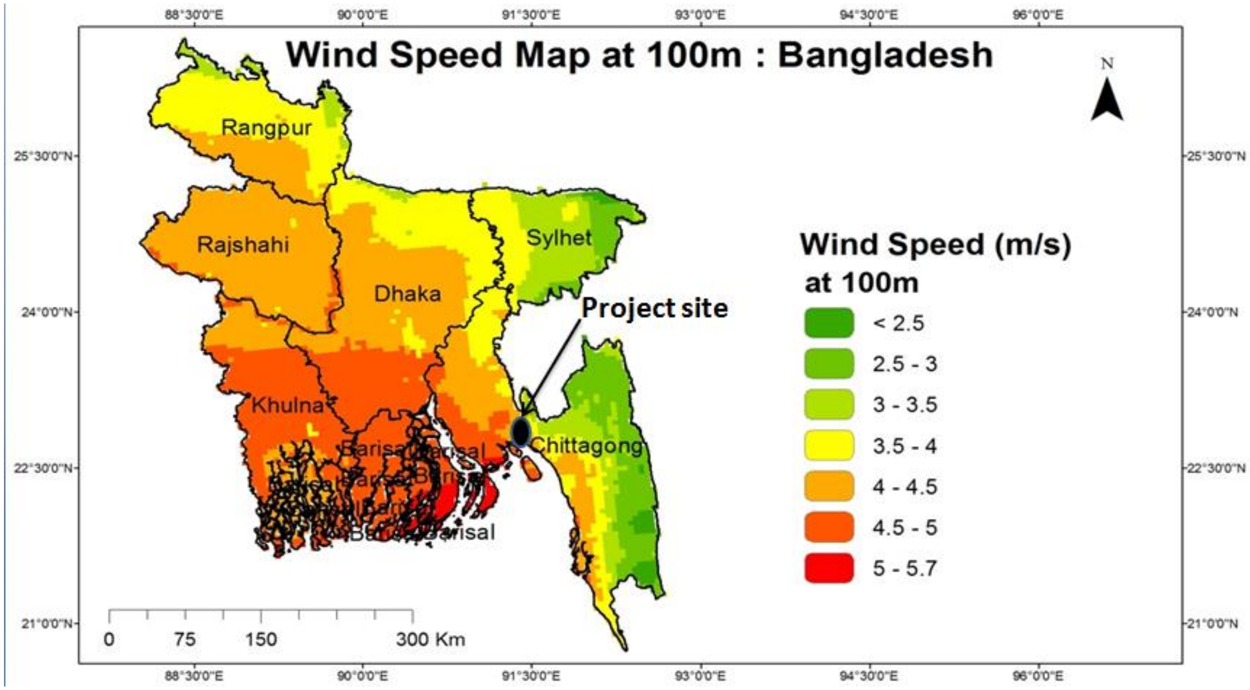
Figure 29: *Digital elevation map of the Region of Interest (RoI)*



Source: *Simulation*

Based on the above methodology and data sets, a mesoscale wind speed map has been drawn at 100m elevation for entire country and has been presented in below figure:

***Figure 30:** Meso-scale wind speed map at 100m elevation for entire country*



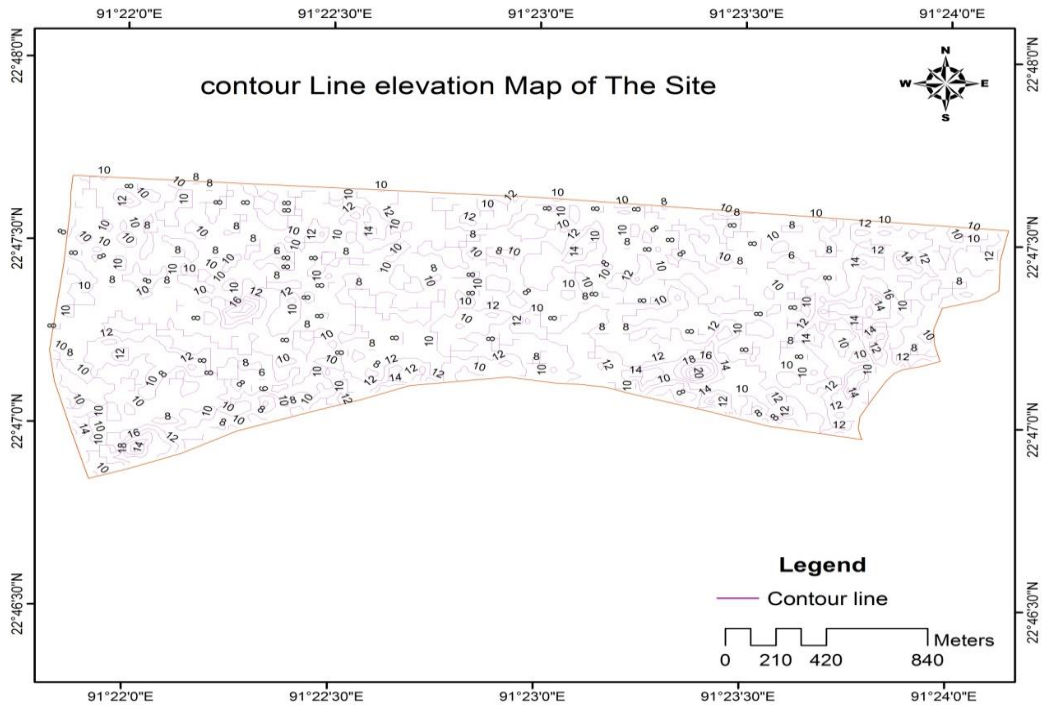
***Source:** Simulation*

On observing the potential areas of higher wind speeds, the exercise of ground measurements are performed, but in our case the potential area has already been identified so the micro-scale modelling has been performed for that RoI.

4.3 Region of Interest (RoI)

The project is located in Sonagazi upazilla of Feni district, Chittagong division of Bangladesh, which is located on a flat terrain. The elevation of the site above mean sea level (MSL) varies from 0 m to 25 m. The site lies on small scale flat terrain and is surrounded with very small and rare plants or vegetation. It has been informed that the site gets water filled during monsoon months. The site location map is shown in figure below:

Figure 31: *Contour map for RoI*



Source: *WFMS*

On physical verification of the site, Micro-scale modelling has been carried out to assess the wind potential for RoI considering best in class wind generators with optimised turbine to turbine spacing.

4.4 Micro-scale modeling for RoI

4.4.1 Boundary layer wind mapping model (BLWMM)

The boundary layer wind mapping model creates a hypothetical field of wind speeds at boundary layer termed as boundary layer wind (BLW) for an area much larger than the RoI.

The following datasets were used in this model:

i. Processed NCEP/NCAR and MERRA reanalysis wind data;
ii. WFMS internal database of wind speed;
iii. Land use land cover database from GLC2000 project and;
iv. Digital elevation model.

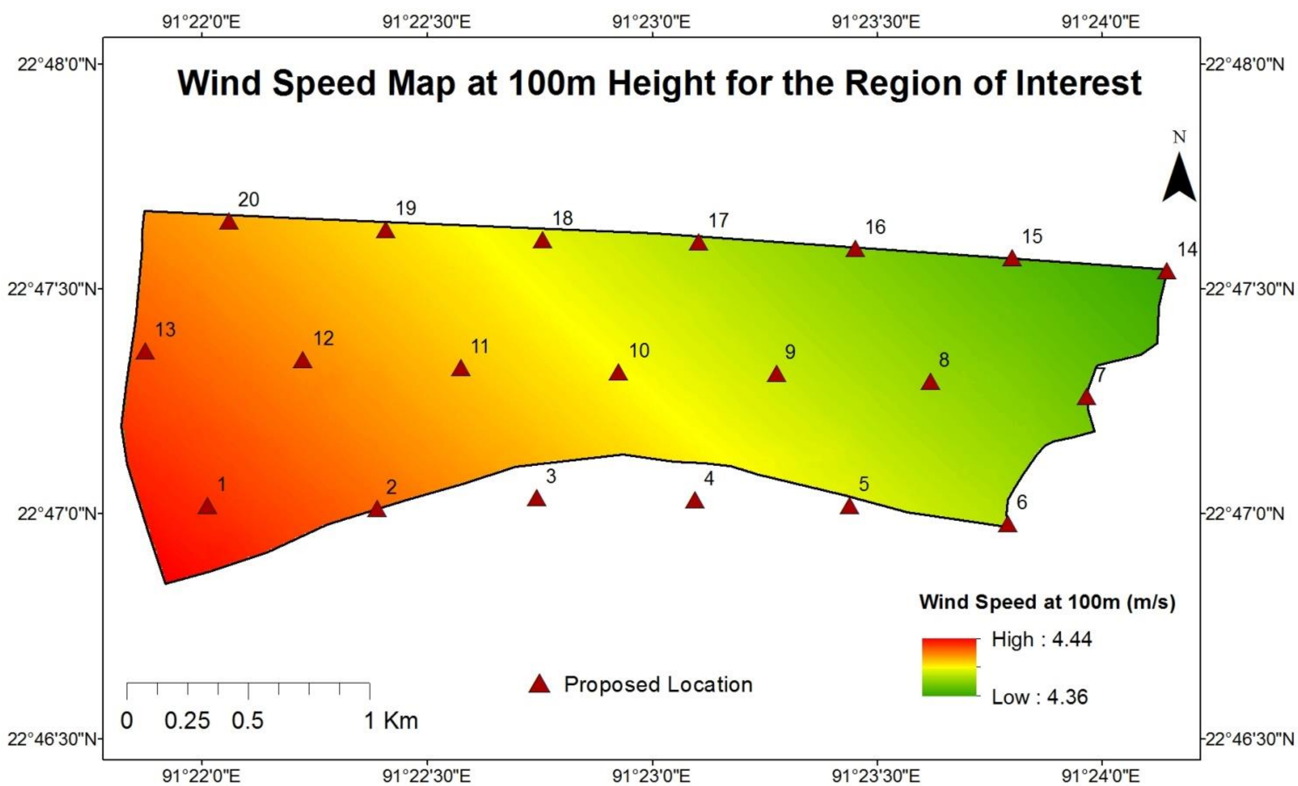
4.4.2 Datasets Processing

The long term NCEP/NCAR and MERRA reanalysis data, LULC database and DEM etc. were processed in the required format to be taken as an input in the BLWMM. The long term measurements are available over the last 68 years or so. It is assumed that BLW is free of disturbances from local terrain, vegetation, settlements and buildings. In the past, BLWMM has been validated by WFMS at the country level for India, Malaysia and Kenya to yield an error of the order of 9% and below.

4.4.3 WFMS meso map assessment model (WMMAM)

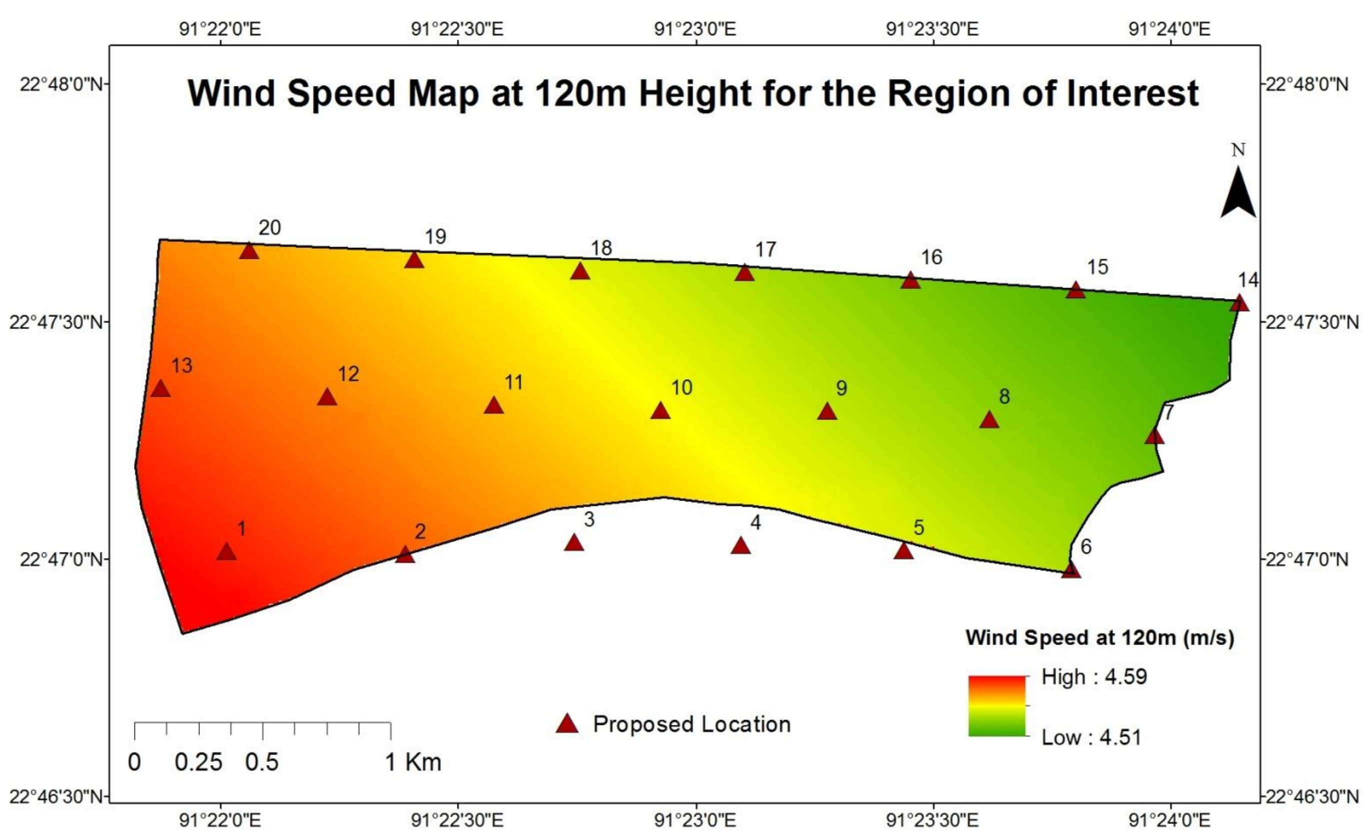
In this task, the BLW is mapped on to every cell in the grid (RoI) at 1 square kilometre resolution to arrive at mean wind speed at height of 100 and 120 m. a.g.l. The mean annual wind speed maps at 100m & 120m heights respectively are shown in below figures:

Figure 33: *Long term wind speed at 100m height for the RoI*



Source: *Simulation*

Figure 33: *Long term wind speed at 120m height for the RoI*



Source: *Simulation*

Based on the micro-scale modelling for the RoI, the long term mean wind speed at 100m height is assessed from WMMAM to 4.47 m/s and same has been used for energy prognosis.

***Note:** WFMS has done the comparative analysis of the used data provided 6 months data and following are outcome of the study:*

- *New dataset:* The new data set provided to WinDForce by the client is inferred to be the weather station data which details about DNI (Direct Normal Irradiance), DHI (Diffuse Horizontal Irradiance), GHI (Global Horizontal Radiation) and also wind data from an anemometer at 10m height. For a period of about 6 months, from 06 June 2017 till 30 November 2017 (*179 days*), the ***wind speeds have been recorded at 8m & 10m*** (vertical wind speed profile). Also, calibration reports for the wind sensor are not available. This is required to ensure that the wind sensor is calibrated and recording without any malfunction
- *Old dataset:* Windforce draft report, vide December 2017, has been shared that was based on the wind speeds at 100m height.
- For any wind project it is always recommended to use wind recorded at hub height level.
- Technically, the anemometer used for capturing the wind data as provided in the new dataset, is not suggested to be used for Wind Resource Assessment because:
  - For WRA minimum of 1 complete year data should be used of wind pattern at 100m height, and the new provided data set was only for 6 months and was at only 8 – 10 m height.
- For further detail on data comparative study, refer separate comparative study report, that is with Appendix M and N.

4.5 Analysis of wind power plant

The Identification of a potential site, turbine selection and its micrositing are the keys for any wind energy project. The selection of site not only depends upon the average wind speed but also on various other parameters like topography, roughness class, natural or man-made obstacles in the vicinity, connectivity for transportation as well grid, etc.

Typically for the selection of an onshore wind turbine, the identification of the wind class, Weibull distribution and the roughness class drives the selection of wind turbine models. The optimisation of cut-in speed and rated wind speed are the critical decisions for a low wind regime area.

In this task, the potential capacity of the site was assessed considering the trade-off between performance of wind turbines and land utilization per megawatt of capacity installed. The three best in class wind generators: Gamesa-G114-2.0MW, Vestas-V110-2.0 MW and Suzlon-S111-2.1MW models have been considered while estimating the long term energy yields as it represents predominant wind technology and appropriate WTG class suited at the site. These WTG models are mainstream IEC-61400 fully certified turbine. Micrositing was carried out with both the above models with turbine spacing criteria i.e. 5D x 7D to arrive at an optimal layout of the wind-farm. The model optimized the positioning of WTGs considering the gross energy yield, spacing criteria and existing terrain. The respective power curves for the selected WTG Models – Gamesa G114, Vestas V110 - 2 MW and Suzlon-S111-2.1MW Power Curves are shown in below figures considering standard air density.

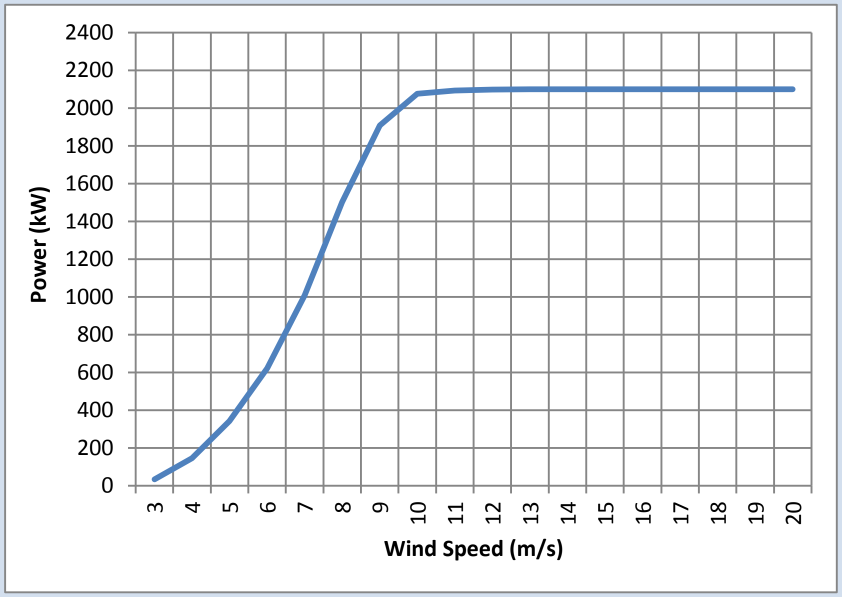
Figure 34: *Power Curve of Gamesa G114 at standard air density (1.225 kg/m^3)*

Wind Speed (m/s)	Power (kW)
3	33
4	146
5	342
6	621
7	1008
8	1501
9	1909
10	2076
11	2093
12	2099
13	2100
14	2100
15	2100
16	2100
17	2100
18	2100
19	2100
20	2100

Technical Specification

Rotor Diameter : 114m

Hub height : 106m



Source: *Gamesa*

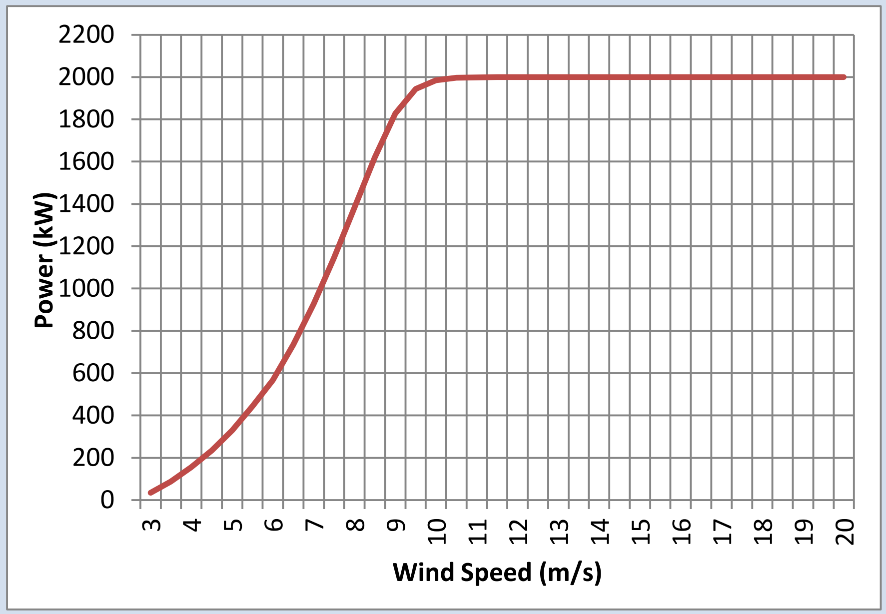
Figure 35: *Power Curve of Vestas V110 at standard air density (1.225 kg/m^3)*

Wind Speed (m/s)	Power (kW)
3	35
4	155
5	329
6	566
7	928
8	1381
9	1827
10	1985
11	1999
12	2000
13	2000
14	2000
15	2000
16	2000
17	2000
18	2000
19	2000
20	2000

Technical Specification

Rotor Diameter : 114m

Hub height : 110m



Source: *Vestas*

The analysis and simulations shows the 20 best possible locations for install WTGs of considered model and capacity.

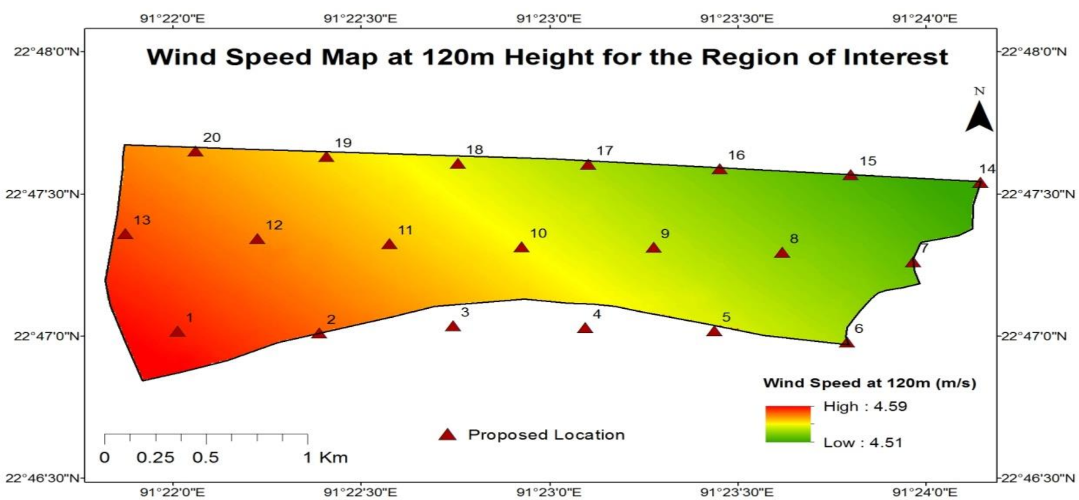
The potential capacity with above WTG models and spacing criteria is given in below table and optimized positions of the WTGs has been shown in the below figure.

Table 18: *Potential capacity with different WTGs model and spacing criteria at the entire site*

WTGs Model	Spacing Criteria	Potential Capacity at the entire site	Number of WTGs
Gamesa-G114 2.0MW	7D x 5D	40 MW	20
Vestas-V110 2.0 MW	7D x 5D	40 MW	20
Suzlon-S111 2.1 MW	7D x 5D	40 MW	20

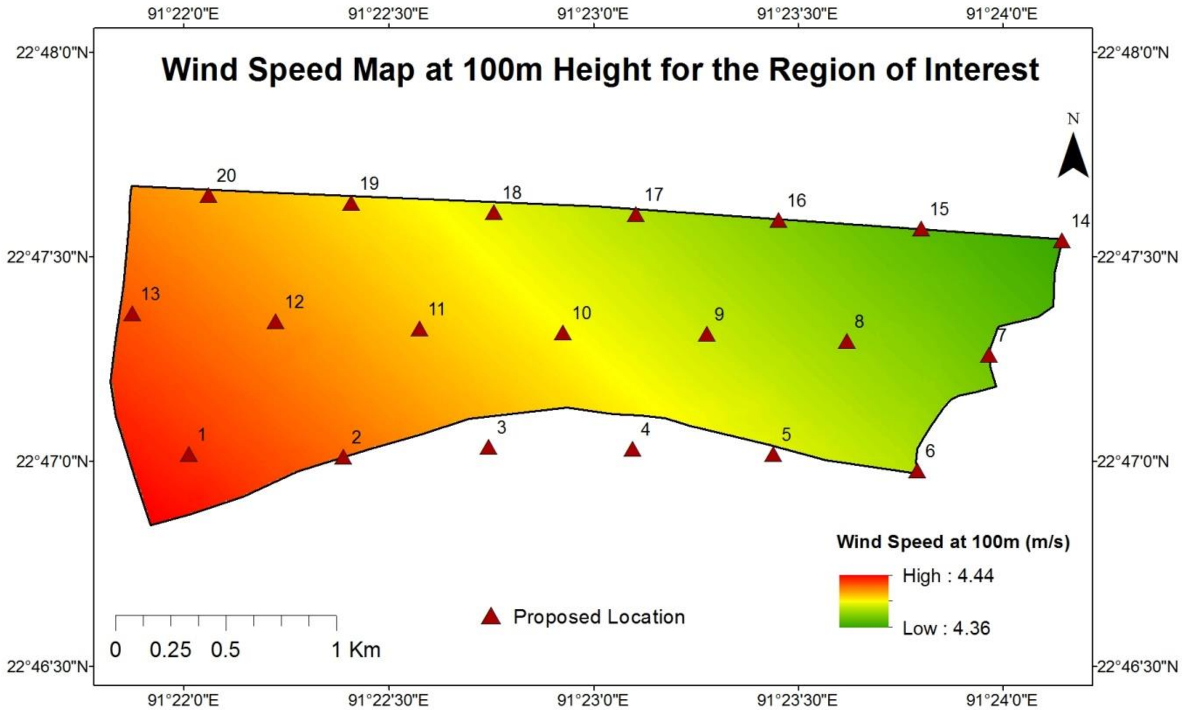
The optimised layout of the site using Gamesa-G114-2.0MW, Vestas-V110-2.0MW and Suzlon-S111-2.1MW (7D x 5D spacing criteria) has been presented with long term mean wind speed at different vertical heights of 100m and 120m in the below figures.

Figure 36: *Optimized layout of Wind turbine generators with Long term mean wind speed at 120m*



Source: *Simulation*

Figure 37: *Optimized layout of Wind turbine generators with Long term mean wind speed at 100m*



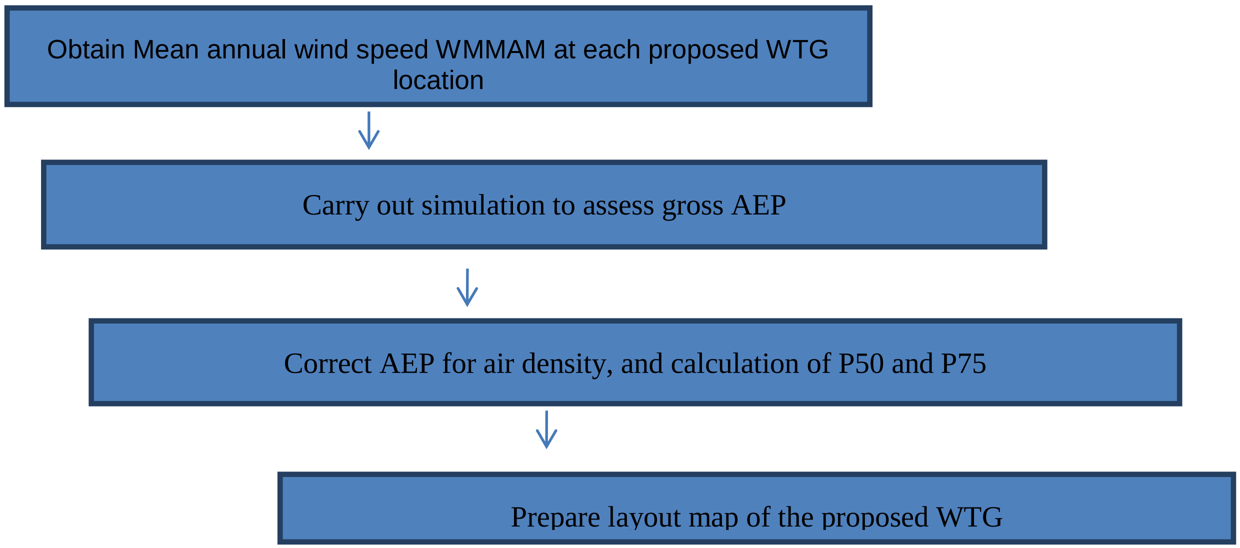
Source: *Simulation*

4.6 Wind energy yield assessment

The wind energy assessment provides information about annual energy production (AEP) at the wind farm level consisting of 20 nos. of wind generators after optimising the location. The figures for gross & net AEP, net PLF w.r.t P50 and P75 are derived for Gamesa-G114-2.0MW, Vestas-V110-2.0MW and Suzlon-S111-2.1MW model WTG power curves with spacing criteria of 5D x 7D are used to arrive at AEP. The various uncertainties drawn in BLWMM and WMMAM model which includes uncertainty pertaining to data modelling, data use, terrain and historical are assessed. The total uncertainty is applied on AEP for estimating PLF at different probabilities of exceedence. In the estimation of net AEP the machine availability, grid availability and transmission loss are considered in accordance with best industry practice.

The process involved in assessing AEP is described through the process – flow diagram shown in below figure.

Figure 38: *Process-flow for assessing AEP*



Source: *WFMS*

The AEP of the wind farm is calculated based on the followings shown in below table:

Table 19: *Outline of inputs for computing of annual energy production*

Wind Data	Mean annual wind speed derived from WMMAM
Power Curve	Gamesa-G114-2.0MW, Vestas-V110-2.0MW and Suzlon-S111-2.1MW model WTG at Standard Air Density 1.225 kg/m3
Site Air Density	Calculated by WFMS at hub-height of WTGs

4.6.1 Evaluation of site

On considering the optimised WTG location through micrositing, the best 20 locations have been identified (across the entire site area, if no other use of land would be there) as shown in below table:

Table 20: *Optimal WTG positions with three WTGs model as per different spacing criteria*

WTG Models	**Gamesa G114 2.0 MW, Vestas V110 2.0MW and Suzlon S111 2.1MW**		
Turbine spacing **c**riteria	**7D x 5D**		
WTG No	**Lat**	**Long**	**Elevation(m)**
01	22.78364	91.36688	7
02	22.78353	91.37317	8
03	22.78395	91.37909	2
04	22.78386	91.38495	4
05	22.78365	91.39068	6
06	22.78299	91.39655	5
07	22.78771	91.39947	5
08	22.78831	91.39365	7
09	22.78857	91.38797	6
10	22.78859	91.38213	7
11	22.78881	91.37629	7
12	22.78908	91.37042	7
13	22.78945	91.36492	6
14	22.79282	91.39671	7
15	22.79236	91.40245	7
16	22.79316	91.3909	7

17	22.79342	91.38508	7
18	22.79349	91.3793	8
19	22.79387	91.37348	8
20	22.79421	91.36769	7

4.6.2 Calculation of wind farm energy yield

PLF values at probabilities of exceedance (PoE) P50 and P75 and gross & net AEP using Gamesa G114 2.0 MW, Vestas V110 2.0 MW and Suzlon S111 2.1 MW WTG models with spacing criteria of 5D x 7D have been derived at the wind farm level consisting all identified 20 WTG locations at the site is given in below table.

Table 21: *Estimated gross and net AEP of wind farm considering 20 WTGs*

WTGs Model	PoE	*Gross AEP (GWh/year)	*Gross PLF (%)	**Net AEP (GWh/year)	**Net PLF (%)
Gamesa G114-2MW	P50	66.46	18.97%	57.93	16.53%
Gamesa G114-2MW	P75	52.91	15.10%	46.12	13.16%
Vestas G110-2MW	P50	62.73	17.90%	54.68	15.60%
Vestas G110-2MW	P75	49.18	14.03%	42.87	12.23%

** Gross PLF is assessed using wind speed derived from meso-scale modeling at 100m hub height for site.*
*** Net PLF after MA=0.96, GA=0.97 and TL factor = 0.965 and Array losses = 0.97 has been considered as per industry practices.*

4.6.3 Evaluation of results and uncertainty

The uncertainty pertaining to micro-scale modelling is high as compared to ground measured wind resource assessment. The various uncertainties considered here are mentioned in below table:

***Table 22:** Uncertainty for energy with three selected WTG models for 20 years period*

Type of Uncertainty	Parameters	Uncertainty on AEP [%] (20 Years)
Historical wind speed variability	Energy Yield	15
Anemometry	Energy Yield	0
Topographic model	Energy Yield	0.15
Wake loss model	Energy Yield	1
Correlation	Energy Yield	3.5
Power curve	Energy Yield	4
Vertical extrapolation	Energy Yield	4
Horizontal extrapolation	Energy Yield	2
Modeling	Energy Yield	5
Data uncertainty	Energy Yield	10
Total uncertainty [%]	Energy Yield	19.98
Future uncertainty [%]	Energy Yield	4.47
Overall Uncertainty [%]		20.09

4.6.4 Founding Structure

Figure 39: *Elevated Founding Structure*

Source: *WFMS*

The issue lies with the water ingress in the area which may affect the construction and operation of foundation structure of machines. There have not been too many instances of wind turbine foundations of on-shore remaining inundated in standing water for more than 24 hours. But this issue can be partially solved by making the turbine foundation base slightly elevated on the normal ground and using fast-setting marine grade RCC for the foundations. Similar construction techniques are routinely followed for other water-immersed infrastructures like railway bridges, highways and even HT towers passing over water bodies like rivers and shallow water bodies and this practice can be incorporated here.

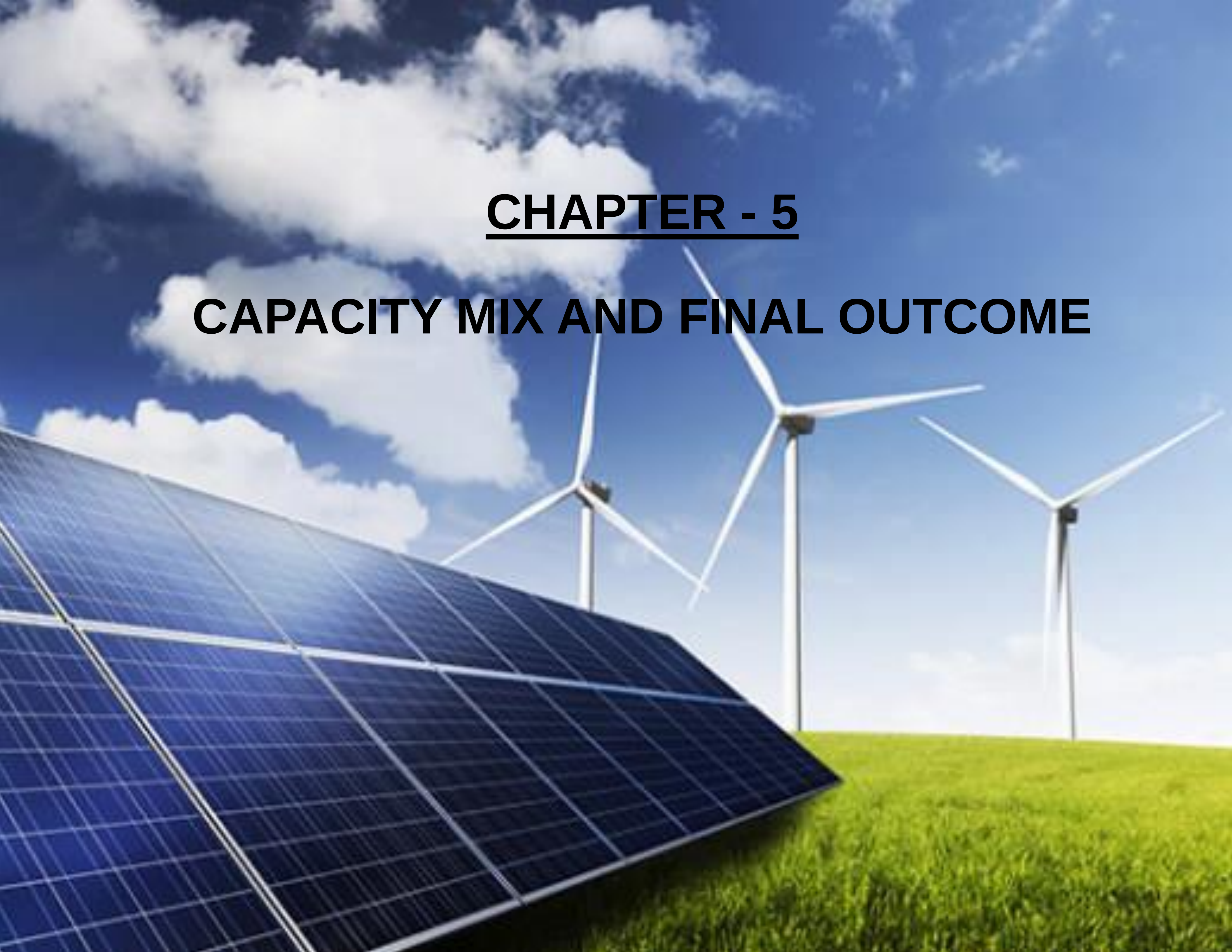
At certain wind projects in India, OEMs have innovated by providing a platform for the entire electrical DP yard and this practise can be incorporated at Sonagazi site for both the solar and wind sections.

Design scheme for elevated DP yard for wind turbine is shown this image. Similar scheme can be adopted for containerised Inverter solution for solar component.

This arrangement will also protect against damage from flash floods, excess rainfall and malicious damage by humans. Small grazing animals who manage to enter solar PV and wind area will also be prevented from damaging the CT, PT and relays. Unskilled labours working to clear shrub growth under the PV installed areas and wind area will also be safe and at the same time they will be prevented from accessing any of the HT side area.

CHAPTER - 5

CAPACITY MIX AND FINAL OUTCOME



Chapter 2, 3 and 4 shows the site assessment, resource estimations, suitable technology and system and energy yield analysis for solar PV and wind energy. Further in this Chapter all possible capacity mix options have been assessed (technical and financial) and presented, and based on assessment, site suitability & requirements one Option out of all assessed options has been recommended for the site i.e. Option 7- only 200 MWac solar PV with no wind this recommended option shall have around 25% of total land area for livelihood activity in distinct manner e.g. Intensive Fishery.

The recommended final option would be “200 MWac solar PV with Intensive Fishery on balance (298 acre) land without wind”. It would be developed in two phases:

1.) Phase-I (EPC mode, EGCB Ownership): 50 MWac solar PV with 230 kV pooling SS, associated infrastructure, dike and approach road development.

2.) Phase-II: (IPP Ownership): 150 MWac solar PV with associated infrastructure and dike.

Note:

1. *Detailed project structuring will be provided as task-5 deliverable of this assignment.*
2. *Environmental and Social Impact Assessment (ESIA), Disaster Impact Assessment (DIA) and Resettlement Action Plan (RAP) of the project will be provided as task-4 deliverable of this assignment.*

Before defining the hybrid system we have considered the mutual influence of solar PV and wind system on each other.

5.1 Mutual influence of wind and solar PV

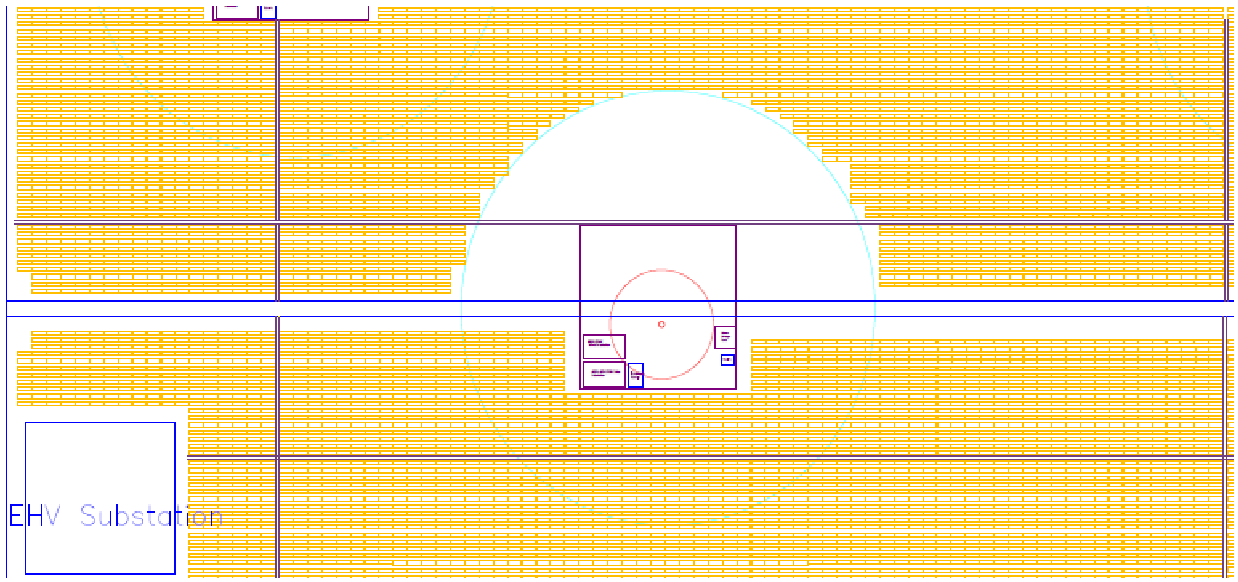
It is envisioned that the major interference of the system will be from the flickering and shadowing effect of the wind turbine blades on the solar PV area. Our design considers that the following points are considered while calculating the quantum of area which is to be left vacant around the wind turbine:

- Falling distance of the turbines = (length of tower + height of the nacelle + radius of the blade) x 1.10, this is the area to be compulsorily kept vacant around the turbines where no PV modules can be installed. As a standard industry practise, the wind turbine switch-yard would be usually installed here but in this proposed project case we can use this area for the water tanks for module cleaning and/or other small components of the module cleaning system.

- An entire stretch of land mostly in the northern, western and eastern part of the land patch. The effect of wind turbine shadow will be on these areas, if install solar PV modules here.

- Additional land for pathways for crane movement.

Figure 40: *Proposed block level layout of Wind-Solar PV Hybrid plant*



Source: *Simulation*

5.2 Capacity Options

The study identified the possible capacity mix options for the site, out of which one option has been recommended that is *Option 7 - "272 MWdc solar PV with fishery activity in the remaining land in distinct manner without wind"*.

The LCOE comparison of all options is based on concessional finance conditions as described in section 7.1 and applied during Phase 1. Moreover, revised cost figures for the dike and power evacuation infrastructure compared to the reference case analysis have been considered. Following are the identified capacity mix options for the site:

5.2.1 Option 1 (reference case)

Option 1 is 100 MWac (136.08 MWdc) solar PV plant and 24 MWac wind energy system and no additional use of land.

Following table shows the results of Option 1:

Table 23: *Option 1 assessment summary*

Parameter	Unit	Option 1 (Reference Case)	
		Solar PV	Wind
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model	
Capacity	MWdc	136.08	
	MWac	100	24
	Total MWac	124	
Net Energy Yield	GWhr/yr	196	31
Total Area	Ha	135	26
CAPEX	m USD	130	36
OPEX	m USD	2	0
LCOE	USD cents / kWh	11.32	19.53

Weighted Average LCOE for PV and wind	12.53

5.2.2 Option 2

In option 2 100 MWac Solar PV, 10 MWac wind power and additional 54 MWac solar PV in between shadow free area of WTGs.

Following table shows the results of Option 2:

Table 24: *Option 2 assessment summary*

Parameter	Unit	Option 2	
		Solar PV	Wind
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model	
Capacity	**MWdc**	209.56	
	MWac	154	24
	Total MWac	178	
Net Energy Yield	**GWhr/yr**	301	31
Total Area	**Ha**	207	26
CAPEX	**m USD**	184	35
OPEX	**m USD**	3	0
LCOE	**USD cents / kWh**	10.28	18.56
Weighted Average LCOE for PV and wind		11.11	

5.2.3 Option 3

Option 3 is only 262 MWac solar PV plant and there is no wind energy system. Entire proposed site will be utilized for only solar PV system installations.

Following table shows the results of Option 3:

Table 25: *Option 3 assessment summary*

Parameter	Unit	Option 3 (full solar PV without wind and fishery)
		Solar PV
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model
Capacity	**MWdc**	356.53
	MWac	262
	Total MWac	262
Net Energy Yield	**GWhr/yr**	514.51
Total Area	**Ha**	352.57
CAPEX	**m USD**	292.42
OPEX	**m USD**	4.21
LCOE	**USD cents / kWh**	9.43

5.2.4 Option 4

In this option 4, 172 MWac (234.05 MWdc) Solar PV and 10 MWac wind power project is proposed in distinct installation manner along with additional utilization of the 26% of the entire land for livelihood purpose e.g. fishery (Intensive Fish culture has been considered for this analysis, and the cost and revenue of fishery has not been considered in financial analysis).

Following table shows the results of Option 4 (solar PV-wind hybrid project) at the proposed site:

Table 26: *Option 4 assessment summary*

Parameter	Unit	Option 4	
		Solar PV	Wind

Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model	
Capacity	MWdc	234.05	
	MWac	172	10
	Total MWac	182	
Net Energy Yield	GWhr/yr	338	13
Total Area	Ha	231	11
CAPEX	m USD	208	14
OPEX	m USD	3	0
LCOE	USD cents / kWh	10.30	17.82
Weighted Average LCOE for PV and wind		10.61	

Option 4 (in two Phases)				
Parameter	**Unit**	**Phase-1**	**Phase-2**	
		Solar PV	**Solar PV**	**Wind**
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	Gamesa G114 2.0MW Model
Capacity	MWdc	68	166	
	MWac	50	122	10

	Total MWac	50	122	10
Net Energy Yield	GWhr/yr	101.36	247.3	12.78
Total Area	Ha	67	164	7DX5D
CAPEX	m USD	80.64	155.86	13.71
OPEX	m USD	0.94	2.05	0.198
LCOE	USD cents / kWh	10.35	10.29	17.82
Weighted Average LCOE for PV and wind		10.61		

Since 26% livelihood area will be used for Intensive fishery in this Option, the following Intensive assumptions have been considered in this analysis:

***Table 27:** Intensive fishery in Option 4*

Option 4				
In Intensive Fish Culture				
	Phase 1	**Phase 2**	**Unit**	**Remark**
Area	76	186	Acres	As per Local and International Fishery Expert
Production	3040000	7440000	KG/year	As per Local and International Fishery Expert @ 40 MT / Acre / year
OPEX	60800000	148800000	Taka/year	As per Local and International Fishery Expert @ 80 BDT / kg of production
Revenue	425600000	1041600000	Taka/year	As per Local and International Fishery Expert @ 140 BDT / kg of production
Capex	912000000	2232000000	Taka	As per Local and International Fishery Expert @ 15 BDT / kg of production

5.2.5 Option 5

Option 5 has fish farming beneath the solar PV modules. Bangladesh local fishery experts were consulted for designing the fish farming beneath the proposed solar PV. This Option 5 is proposed to be developed in two phases (as proposed for Option 4), Phase-I will have only 50 MWac solar PV with relevant infrastructure like Site approach road, Dike for Phase-I, ponds, office area, platforms etc. Phase-II will have remaining 116 MWac solar PV with 10 MWac wind capacity along with pooling SS for entire project, Dike for Phase-II, platforms etc.

Following table shows the results of Option 5 (solar PV-wind hybrid project with fish farming (semi Intensive fish culture) beneath the solar PV module) at the proposed site:

Table 28: *Option 5 assessment summary*

Parameter	Unit	Option 5	
		Solar PV	Wind
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model	
Capacity	MWdc	225.89	
	MWac	166	10
	Total MWac	176	
Net Energy Yield	GWhr/yr	327	13
Total Area	Ha	291	11
CAPEX	m USD	222	15
OPEX	m USD	4	0
LCOE	USD cents / kWh	11.49	18.07
Weighted Average LCOE for PV and wind		11.76	

Option 5 (in two phases)				
Parameter	Unit	Phase-1	Phase-2	
		Solar PV	Solar PV	Wind
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	Gamesa G114 2.0MW Model
Capacity	MWdc	68	157	
	MWac	50	116	10
	Total MWac	166		10
Net Energy Yield	GWhr/yr	98.51	228.54	12.79
Total Area	Ha	87	203	11.02
CAPEX	m USD	68.30	154	14.69
OPEX	m USD	1.190	2.476	0.198
LCOE	USD cents / kWh	11.50	11.48	18.07
Weighted Average LCOE for PV and wind		11.76		

Semi intensive fish culture has been considered in this Option 5 (beneath the solar module), hence following Semi-Intensive assumption has been considered in this analysis:

Table 29: *Semi intensive fishery in Option 5*

Option 5				
In Semi Intensive Fish Culture				
	Phase 1	Phase 2	Unit	Remark
Area	240.698	567.26	acres	As per Local and International Fishery Expert
Production	962792	2269040	KG/year	As per Local and International Fishery Expert @ 4 MT / Acre / year
OPEX	14441880	34035600	Taka/year	As per Local and International Fishery Expert @ 60 BDT / kg of production
Revenue	134790880	317665600	Taka/year	As per Local and International Fishery Expert @ 140 BDT / kg of production
Capex	192558400	453808000	Taka	As per Local and International Fishery Expert @ 20 BDT / kg of production

As per Fishery experts inputs we have designed the layout of Option 5 which caters the relevant requirements for fish farming beneath the solar PV, as follows:

1.) Optimum area distribution for fishery solar PV, wind and other relevant activities: Due to initial stage proper maturing of fish eggs we have not considered the installation of solar PV on Egg and Fingerlings ponds, solar PV installation will come only on Market Size Maturing Ponds. Following table shows the area distribution for Option 5:

S. No.	Area Description	Phase -I (Acres)	Phase -II (Acres)	Remark
1	Egg Pond Area	2.4814	5.8480	-
2	Fingerlings Pond Area	4.9629	11.6936	-
3	Market Size Maturing Pond Area	240.6983	567.2558	-
4	Solar PV Plant Area	226.5050	538.1708	Solar PV plant is installed only on market size

S. No.	Area Description	Phase -I (Acres)	Phase -II (Acres)	Remark
				maturing pond area
5	Wind Turbine Protection Area	12.5808	61.7226	-
6	Truck Loading Area	0.4942	0.9884	-
7	Dike Area With 10 Mtr. Road	23.2540	61.0987	-
8	Area For Pooling SS	-	4.9779	-
9	Office Area	0.2471	-	-
10	Total Area	284.7187	713.5849	-

2.) Optimum sun light for aqua culture: Following table shows the proposed required sunlight fulfilment along with solar PV module installation and decrease in solar PV capacity because of provision of more row spacing for fishery (because of the fishery activity requirements the solar PV plant will be having updated – 6 m row spacing, 11.6 m pitch and 15° tilt angle):

Table 30: *Aquaculture sustaining optimum parameters along with solar PV system*

Sr. No.	Month	Optimum Pitch Per Month	Sunlight Area Available On Each Row In Sq.Mtr	No. Of Rows	Total Area For Sunlight Per Month	Total Module Area For 1 Mw In Sq. Mtr	Sunlight Area Available Per Month
1	January	8	510.353	8	4082.824	12359	33%
2	February	7.5	582.353	8	4658.824	12359	38%

3	March	6.5	724.353	8	5794.824	12359	47%
4	April	6.5	724.353	8	5794.824	12359	47%
5	May	6.5	724.353	8	5794.824	12359	47%
6	June	6.5	724.353	8	5794.824	12359	47%
7	July	6.5	724.353	8	5794.824	12359	47%
8	August	6.5	724.353	8	5794.824	12359	47%
9	September	6.5	724.353	8	5794.824	12359	47%
10	October	7.5	582.353	8	4658.824	12359	38%
11	November	8	510.353	8	4082.824	12359	33%
12	December	8.5	439.353	8	3514.824	12359	28%
Average Area Available For Sunlight Per Year In 1 MWp PV Plant for fishery							42%
Decrease In Capacity After Increasing Row Spacing In 1 MWp PV Plant for fishery							27%

3.) Optimum elevation of solar PV system for fishery management activity: The elevation of the solar PV system will be 4 m, which will cater the fishery management activity requirement.

As per consultation with fisher expert, above mentioned spacing, elevation and sunlight area are sufficient for fish farming at the site beneath the solar PV modules.

5.2.6 Option 6

In this option 6, 182 MWac (247 MWdc) Solar PV is proposed with fishery (semi-intensive fish culture) beneath the solar modules and no wind power project.

Following table shows the results of Option 6 at the proposed site:

Table 31: *Option 6 assessment summary*

Option 6 (Single Phase)		
Parameter	Unit	Solar PV
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology
Capacity	MWdc	247
	MWac	182
	Total MWac	182
Net Energy Yield	GWhr/yr	360
Total Area	Ha	319
CAPEX	m USD	242
OPEX	m USD	4
LCOE	USD cents / kWh	11.33

Option 6 (in two Phases)			
Parameter	Unit	Phase-1	Phase-2
		Solar PV	Solar PV
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	Fixed-tilt solar PV system based on central inverter and polycrystalline module technology
Capacity	MWdc	72	175
	MWac	53	129
	Total	**182**	

	MWac		
Net Energy Yield	GWhr/yr	98.881	261.03
Total Area	Ha	87.7	231.53
CAPEX	m USD	67.82	173.97
OPEX	m USD	1.190	2.82
LCOE	USD cents / kWh	11.37	11.32
Weighted Average LCOE for PV		11.33	

Semi intensive fish culture has been considered in this Option 6 (beneath the solar module) with no Wind power project, hence following Semi-Intensive assumption has been considered in this analysis:

Table 32: *Semi intensive fishery in Option 6*

Option 6				
In Semi Intensive Fish Culture				
	Phase 1	**Phase 2**	**Unit**	**Remark**
Area	240.698	567.26	acres	As per Local and International Fishery Expert
Production	962792	2269040	KG/year	As per Local and International Fishery Expert @ 4 MT / Acre / year
OPEX	14441880	34035600	Taka/year	As per Local and International Fishery Expert @ 60 BDT / kg of production
Revenue	134790880	317665600	Taka/year	As per Local and International Fishery Expert @ 140 BDT / kg of production
Capex	192558400	453808000	Taka	As per Local and International Fishery Expert @ 20 BDT / kg of production

Optimum area distribution for fishery solar PV and other relevant activities: Due to initial stage proper maturing of fish eggs we have not considered the installation of solar PV on Egg and Fingerlings ponds, solar PV installation will come only on Market Size Maturing Ponds. Following table shows the area distribution for Option 6:

OPTION 6 - Full Solar PV with Fishery (No Wind power project)				
S. No.	**AREA DESCRIPTION**	**PHASE -I (Acres)**	**PHASE -II (Acres)**	**Remark**
1	Egg Pond Area	2.4814	5.8480	
2	Fingerlings Pond Area	4.9629	11.6936	
3	Market Size Maturing Pond Area	240.6983	567.2558	
4	Solar PV Plant Area	226.5050	538.1708	Solar PV Plant is installed only on Market Size Maturing Pond Area
5	Truck Loading Area	0.4942	0.9884	
6	Dike Area With 10 Mtr. Road	23.2540	61.0987	
7	Area For Pooling Ss		4.9779	
8	Office Area	0.2471		
9	Total Area	284.7187	713.5849	

5.2.7 Option 7 (Recommended Option)

In this option 7, 200 MWac (272 MWdc) Solar PV is proposed with utilization of the remaining land for livelihood purpose e.g. fishery (Intensive Fish culture has been considered for this analysis and the cost and revenue of fishery has not been considered in financial analysis).

Following table shows the results of Option 7 at the proposed site (P75):

Table 33: *Option 7 assessment summary*

Parameter	Unit	Option 7 (solar PV with fishery and no wind)
		Solar PV
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind: Gamesa G114 2.0MW Model
Capacity	MWdc	272

	MWac	200
	Total MWac	200
Net Energy Yield	GWhr/yr	392.44
Total Area	Ha	269
CAPEX	m USD	237
OPEX	m USD	3.42
LCOE	USD cents / kWh	10.04

Option 7 (in two Phases)			
Parameter	**Unit**	**Phase-1**	**Phase-2**
		Solar PV	**Solar PV**
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	
Capacity	MWdc	68	204
	MWac	50	150
	Total MWac	200	
Net Energy Yield	GWhr/yr	98.12	294.32
Total Area	Ha	67.3	201.85
CAPEX	m USD	66.37	170.63
OPEX	m USD	0.94	2.48
LCOE	USD cents / kWh	10.18	9.99

Following is Intensive fish culture assumptions:

Table 34: *Intensive fishery in Option 7*

Option 7				
In Intensive Fish Culture				
	Phase 1	**Phase 2**	**Unit**	**Remark**
Area	81.17	48.9	Acres	As per Local and International Fishery Expert
Production	3246800	1956000	KG/year	As per Local and International Fishery Expert @ 40 MT / Acre / year
OPEX	259744000	156480000	Taka/year	As per Local and International Fishery Expert @ 80 BDT / kg of production
Revenue	454552000	273840000	Taka/year	As per Local and International Fishery Expert @ 140 BDT / kg of production
CAPEX	48702000	29340000	Taka	As per Local and International Fishery Expert @ 15 BDT / kg of production

Following table shows the area distribution for recommended Option 7:

Area Assessment (Phase - 1)	
Block	**Area (In Acres)**
Dike	31.40
Natural Stream	26.47
PV Table Area	179.55
Office Area & Cyclone Shelter	0.49
Pooling Sub-Station	4.82
External Road	7.67
Drain	2.75
Fencing	3.77
Intensive Fishery Area	81.17
Total Area	**338.09**
Area Assessment (Phase - 2)	

Block	Area (In Acres)
Dike	44.55
Natural Stream	9.71
PV Table Area	533.87
External Road	12.56
Drain	2.56
Fencing	13.52
Intensive Fishery Area	48.90
Total Area	**665.69**

Note: *Total Solar PV plant area is sum of areas of Dike, Natural Streams, PV table area, Office & Cyclone Building area, Pooling SS, Roads, Drain and Fencing.*

5.3 Recommended Option

Bangladesh is having land scarcity and higher population density per square KM, therefore, to utilize the available land in most optimum way to fulfil country's needs and generation of more livelihood options for the citizens is the major consideration for the GoB.

This project site is also considering the sustainable development – environment benefit through renewable energy, economic benefit through additional power generation and social benefit through livelihood generation.

The detailed assessment and analysis of all the 7 options has given the conclusion that Option 7 is the more appropriate and suitable implementable option for the proposed site (considering all the aspects and requirements).

Rationale for the option recommendation:

c.) Following comparative analysis shows the rationale to choose the Option 7 as the recommended option (Only Solar PV, No wind):

Table 35: *Solar PV V/s Wind project comparative assessment*

Solar PV	Wind
Site is having good solar resource and generation potential. (As per resource potential assessment)	Site is having less wind resource and generation potential.
1 MWdc solar PV would require 2.4 Acres land (1 MWac solar PV would require 3.3 Acres land)	1 MWac wind would require 7.4 Acres land
If 10 MWac wind (74.3 Acres of land) is replaced with complete solar PV then it can accommodate additional ≈30 MWdc solar PV capacity on the same land.	
30 MWac solar PV would produce 58 GWhr per year net electricity	10 MWac wind (using same land as 30 Mwac Solar) would produce 14.9 GWhr per year net electricity
LCOE = 10 USD cents / kWh (As per financial analysis, it does not include the cost and revenue of fishery, but it includes fishery's impacts on foundation, civil & Structure cost).	LCOE = 18 USD cents / kWh
Associated Infrastructure cost: for solar PV need to strengthen the existing 4 m wide road it costs around 23.77 Mn Taka, there is no need of development of a new road or Jetty.	Associated Infrastructure cost: for wind along with solar PV need to develop 9.8 m wide new road (this stretch of road consists of 3 Bridges of 8m, 20m, 30m respectively and 2 Culverts (both of 3m length), it costs around 147.1 Mn Taka. there would be need of detailed study and development of a new road or Jetty.

For the proposed site only solar PV installation with no wind is recommended, based on comparative analysis.

d.) Following comparative analysis shows the rationale to choose the Option 7 as the recommended option (Only Solar PV with Intensive Fishery at open land in distinct manner):

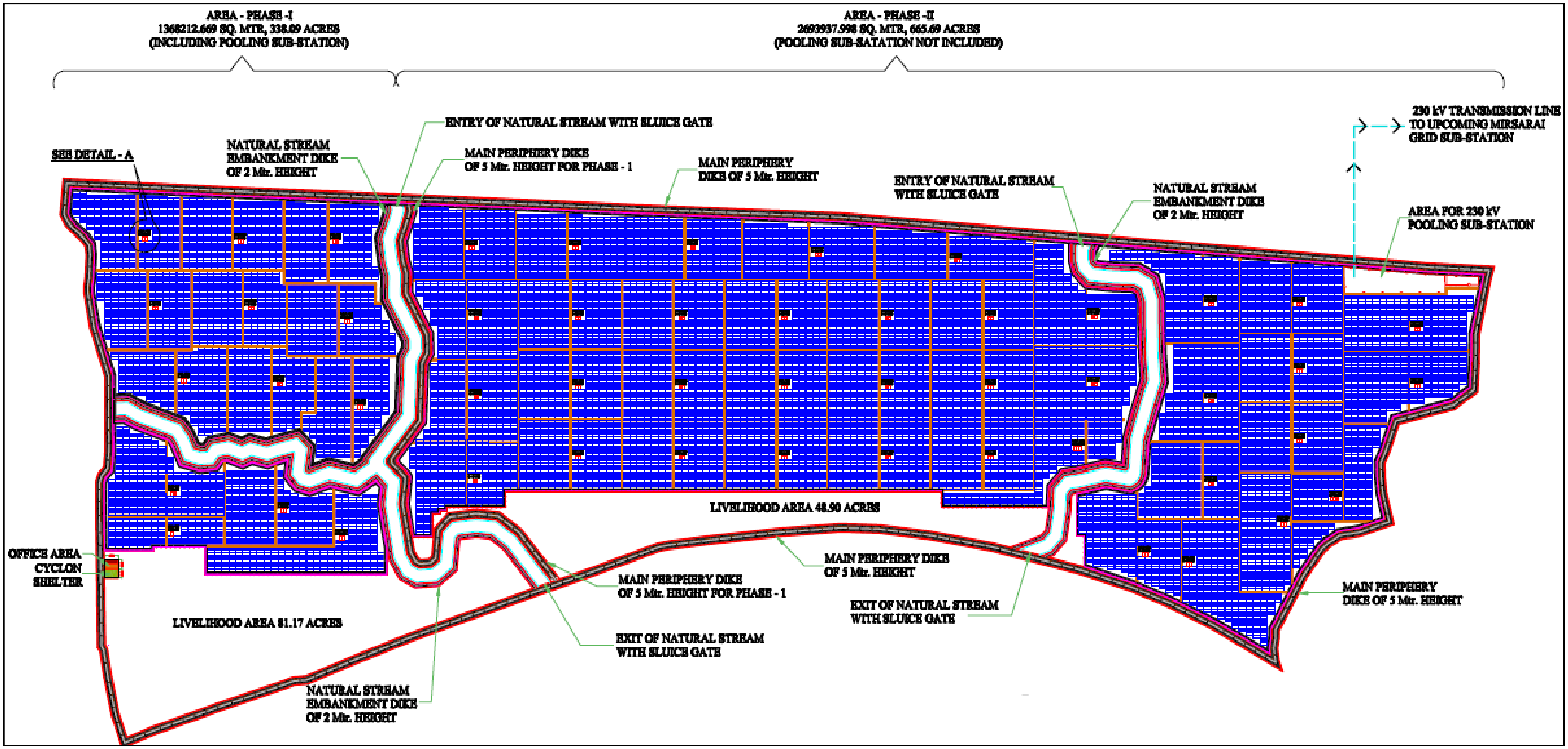
Table 36: *Intensive fishery V/s Semi-intensive fishery comparative assessment*

Parameters	Intensive Fish Culture	Semi Intensive Fish Culture
Production (kg per year per Acre)	40000 @40 MT/acre	4000 @4 MT/acre
OPEX (Taka per year per Acre)	3200000 @80 BDT/kg	240000 @60 BDT/kg
Revenue (Taka per year per Acre)	5600000 @140 BDT/kg	560000 @140 BDT/kg
Capex (Taka per Acre)	600000 (@15BDT/kg	80000 @20 BDT/kg
Operation of Solar Plant	Fish culture independent – solar production can be maximized. No O&M Difficulties	Solar panels will be spaced at a larger pitch. O&M difficulties in accessing panels through a Boat
LCOE of solar plant accommodating fishery specification	10.1 USD cents/kWh	10.8 USD cents/kWh

Intensive fish culture on open land is a better option to Semi-intensive fish culture beneath the panels, due to 10 times better productivity (fish productivity), relatively higher solar generation (in term of units generated), lower LCOE, and less operational complexity.

Conclusion: Based on GoB Bangladesh's requirement of livelihood, site parameters/location, ease in EPC & O&M, financial attractiveness and comparative study, Option 7 comes out as more appropriate option for the proposed site. Hence Option 7 is the recommended option from this feasibility assessment study.
Following figure shows the layout of the recommended Option 7:

Figure 41: *Layout of the recommended Option 7*



Source: *WFMS*

Further in Chapter 6 – Power Evacuation and Off-take, Chapter 7 - Financial Analysis (for solar PV) and Chapter 8 – Economic analysis, Option 7 (i.e. recommended option) has been used to present the analysis and results.

5.4 Project Management Schedule & Permissions

Following is an exemplary project schedule of an illustrative 50 MWac solar PV power project. EPC contractor / developer has to develop a similar schedule and follow it rigorously for timely completion of the project (based on similar project experience).

Table 37: *Project management schedule*

	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13
Activities by PowerCell													
Finalization of DPR	■												
Investment Approval	■												
Preparation of Tender	■												
Floating of Tender	■	■											
Technical Evaluation, Recommendation for Price Bid Opening		■											
Award of Work/LOA			■										
Activities by LSTK													
Site Specific Assessment Studies and Design				■	■								
Supply						■	■	■	■				
Construction of Foundations						■	■	■	■				
Erection of Electrical Components							■	■	■				
Installation									■	■	■		
Commissioning of Entire Project												■	■
Performance Testing												■	■
Training of Manpower for O&M												■	■
Installation Activities													
PowerCell support during installation and commissioning	■	■	■	■	■	■	■	■	■	■	■	■	■

Note: *Relevant site specific studies, design engineering and construction of site approach road & dike shall be done before project installation.*

Certain permits and clearances are required to be obtained by the project developer from different Government and statutory agencies at various stages of development phase of the project.

Permitting and licensing procedures vary depending on plant location and size. For small PV installations, permitting regimes are often simplified and obtained at a local authority level. However large-scale plants can have more extensive requirements that are determined at a national or regional level. The key permits, licences and agreements typically required for renewable energy projects include:

- Land lease agreement
- Planning/land use consents
- Building permits
- Environmental permits
- Grid connection application
- Operator/generation licenses

The list of clearances/permits along with the status is as under (as an exemplary based on similar project experience in the region):

Table 38: *Project development permissions*

Permissions/Licenses	Authority	Tentative timeline
Bid Winning		
Letter of Consent from State DISCOM	DISCOM	45 days
Temporary Electricity Connection on site	State Electricity Board	
LOA from Nodal Agency	Nodal agency	
PBG	Nodal agency	
Implementation Agreement with DISCOM	DISCOM	

PPA	DISCOM	
Land Clearance (Deed/Registry and etc.)	District town Planner/Municipal/Forest Department	6 months
CLU-Change of Land use if it is Forest or Agriculture land	NOC and other required set of documents to attached for CLU.	
	District Town Planner-Revenue Department	
Water Pipeline or Ground Water Clearance from similar department.	Ground water department	
Waste Disposal Clearance	Concern department	
Consent to Establish	Concern department	
Fire NOC	Concern department	45 days
Pollution Control Board	PCB	
Forest Clearance	Ministry of Environment and Forestry (MOEF) (Register in the website and doing needful)	
Grant of Connectivity or Grid Feasibility letter from nearest SS	DISCOM Circle office(SS)	45 days
NOC from DISCOM based on Grant of Connectivity	DISCOM	
Right of Way from TRANSCO	TRANSCO	
State Highway or National Highway Clearance	Concern Ministry and state departments	
CEIG Approval	Concern department	
Leveling of land using blast mode (if applicable)	Permission to be taken from DC	30 days
Third Party Inspection approval to be submitted to DISCOM and Nodal Agency	Third party	
Labor Licenses	Labor department	
Road Entry Permit for Contractors to bring Material to site	Concern department	
Bill of Material Clearance from Nodal Agency in concurrence with DISCOM and TRANSCO	With Order Copy/Agreement Copy stating the quantity and price and technology used. Should comply the ROW and State Grid Code Supply and CEIG Compliance and CEA as well.	15 days
Purchase of Approved Meters	Authorized supplier	5 days

Test Certificate of Meters	Authorized supplier	
CEIG Inspection/MRT (meter reading test department) - Grid synchronization	-	1-5 days
Final NOC from DISCOM	DISCOM	7 days
Commissioning Certificate	Concern department	
New entity formation		
VAT registration	Concern department	45 days
PF registration	Concern department	
ESI Registration	Concern department	
Sales Tax Registration	Concern department	
Professional Tax- Employer and Employee	Concern department	
Import- Export Certificate	Concern department	

Costing of the relevant permits/licenses is subject to concern departments' own procedure and guidance. It varies country to country with required permitting/licenses to set up a large scale grid interactive solar PV power project.

***Note:** Annexure-J shows the solar PV plant maintenance schedule.*

5.5 Operation and Maintenance (O&M)

After assessment of site location and conditions, automatic robotic dry type module cleaning system is proposed for the project. However option is open with client to choose whether to use conventional O&M or Robotic O&M.

The technology (E4) is a water-free cleaning system, meaning that it not only avoids the cost of water, but also the infrastructure that supports it, be it tanker trucks, storage containers, hoses and piping. The E4 removes 99% of soiling on a daily basis using a combination of three factors: A special microfiber that gently wipes soiling away controlled airflow over the panel surface and gravity to ensure soiling is moved downwards and off panel rows.

Figure 42: *Robotic dry type solar module cleaning system*

Source: *www.ecoppia.com*

To ensure that the E4 has the flexibility to respond to sudden weather events means not being reliant on external energy sources. That's why we've designed the E4 to have their own on-board dedicated solar module, allowing the batteries to get quickly charged every morning. A patented eco hybrid technology developed to facilitate a minimal use of the batteries.

It's a smart, sensor-enabled and internet-connected autonomous maintenance solution. Sensors collect weather data, and initiate cleanings based on weather conditions. Machine-learning works to optimize the E4's own maintenance schedule – ensuring that the E4 has over 99% availability for the lifetime of your site.

Monitor and manage site's E4 fleet from anywhere in the world via remote management platforms, where one can initiate cleanings, change schedules, look at historical statistics or drill down into the function of single robots. Management is further enhanced by a simple SMS interface, allowing us to send commands and receive status updates from your mobile phone.

- Cost of Robotic Cleaning System
  - Cost of single piece Robotic Cleaning System = 4500 USD + Taxes
  - Each MW requires = 5 Robotic Cleaning System
  - Cost of Robotic Cleaning System per MW = 22500 USD/MW + Taxes

- Cost of Robotic Cleaning System for Bangladesh Project.
  - Total Solar Capacity as per OPTION-7 = 272 MWdc
  - Total Cost of Robotic Cleaning System = 6120000 USD + Taxes

- O&M cost of the system:
  - The project O&M cost would be around 10% of the project cost, it includes all (replacement, maintenance etc.)

- Any issue regarding Bangladesh Saline & Moist weather condition?
  - They have already installed there Robotic cleaning system in a plant in Tamil Nadu. There is no issue with salinity in the cleaning process.

- Time required in Installation of Cleaning System?
  - 8 months.

- Life of System?
  - 25 years.

- Yielding time consequences due to monsoon in Bangladesh (around 4 to 5 month)?
  - There are no such consequences of 4 to 5 month yielding time.

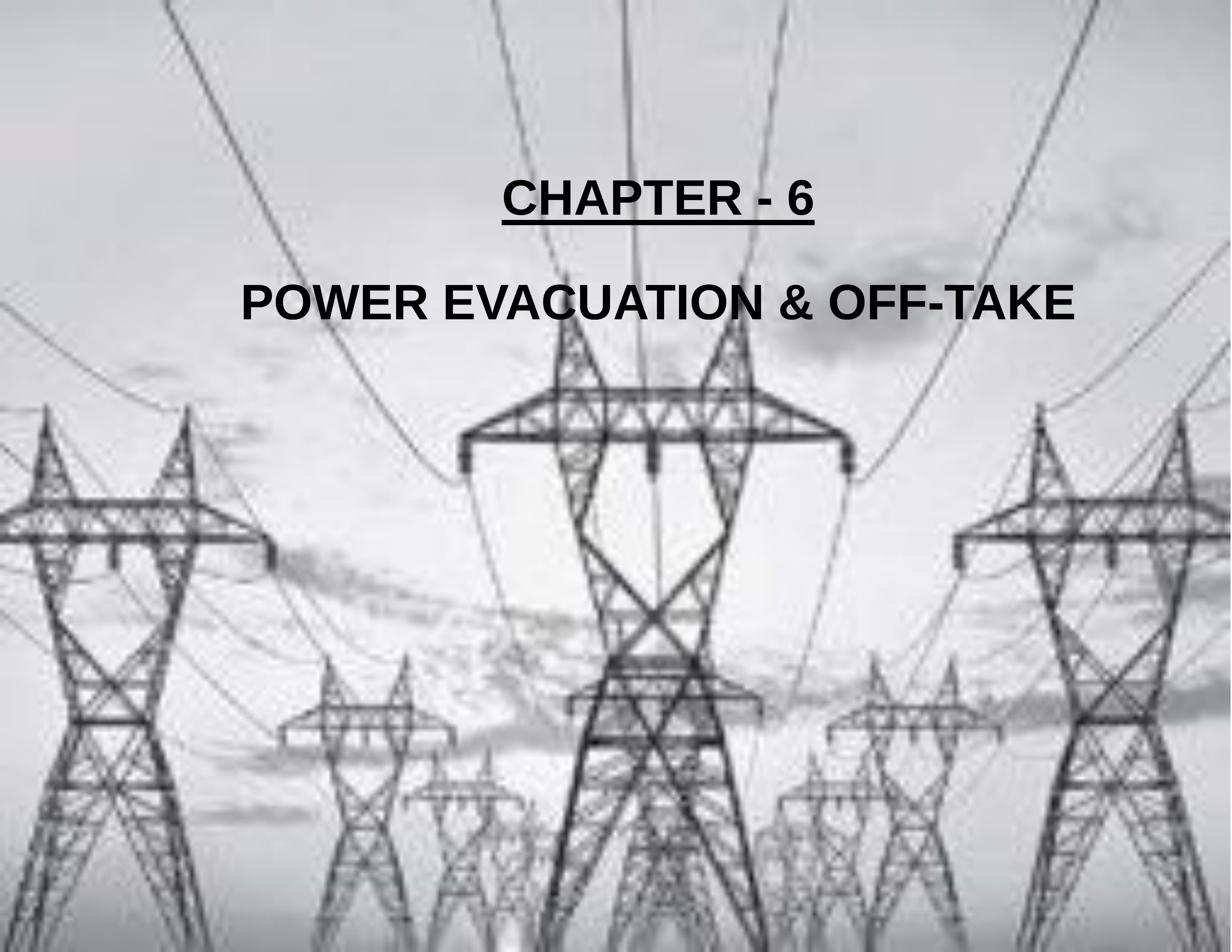
- Availability of system?
  - Their product is easily available.

- Previous experience in such projects?
  - Yes, they have installed and running successfully their system in such coastal area e.g. in Tamil Naidu coastal area, India.

Note: *Above mentioned information are based on discussion with Ecoppia Technology Provider.*

CHAPTER - 6

POWER EVACUATION & OFF-TAKE



6.1 Options for power evacuation of the project

PGCB requires to ensure adequate and reliable power supply for the upcoming economic zone at Mirsarai in Chittagong, to establish transmission infrastructure for transfer of electricity generated from upcoming coal/LNG power plants at Moheskhali and Matarbari to the major load centers and to meet the rapidly growing demand of residential, commercial and industrial consumers in the southern region (in Gopalganj, Satkhira, Faridpur, Khulna, Chittagong and Greater Barisal Districts), as well as other locations throughout Bangladesh. This GSS can be used for this RE project.

This proposed RE project will be developed in two phases, first phase will be 50 MWac solar PV only and second phase will be remaining of solar PV capacity.

As per EIA report Mirsarai Economic Zone-II of BEZA and Tender ICB no PGCB/230KV/MIRSAR-BSRM/SS of PGCB, "Mirsarai Economic Zone is a fully government owned economic zone with an area of approximately 7716 acres under Bangladesh Economic Zones Authority (BEZA). A memorandum of understanding (MoU) was signed between BEZA and PGCB for setting up and maintenance of a grid substation in Mirsarai Economic Zone. PGCB will establish a 230/132/33 kV Grid Substation with provision of extension up to 400 kV in the land provided by BEZA as per MoU. Distance of proposed 50 MW solar power plant site from PGCB grid substation under BEZA is around 9 km. PGCB has invited bid for "Design, Supply, Installation, Testing and Commissioning of 230/33kV GIS Substation at Mirsharai EZ" on 09 August,2017 which will be completed within 18 months from the effective date of contract"

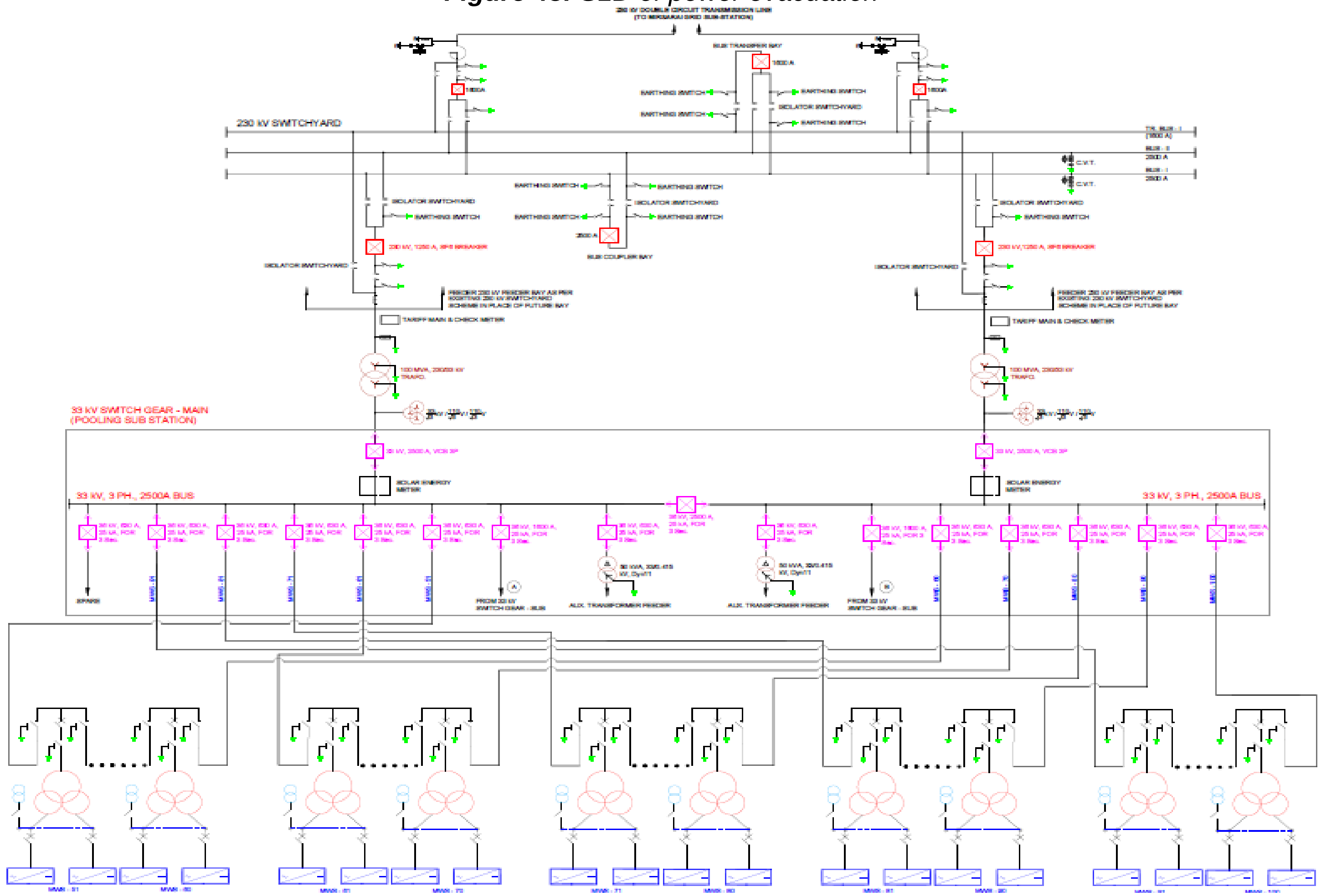
Hence based on discussions and suggestion from PGCB, Mirsarai 230 kV GSS of PGCB Or BEZA substation of PGCB (under construction) can be an option for power evacuation for this RE project. For this feasibility assessment study we have considered Mirsarai 230 kV GSS, however further power evacuation option and arrangement depend on the detailed grid connectivity and stability study of PGCB and client’s decision.

The Generated power from this project will be stepped up to kV level of transmission line and then evacuated through dedicated feeder lines to the pooling SS. The pooling SS should be of 230 kV level to be connected to 230 kV Mirsarai GSS.

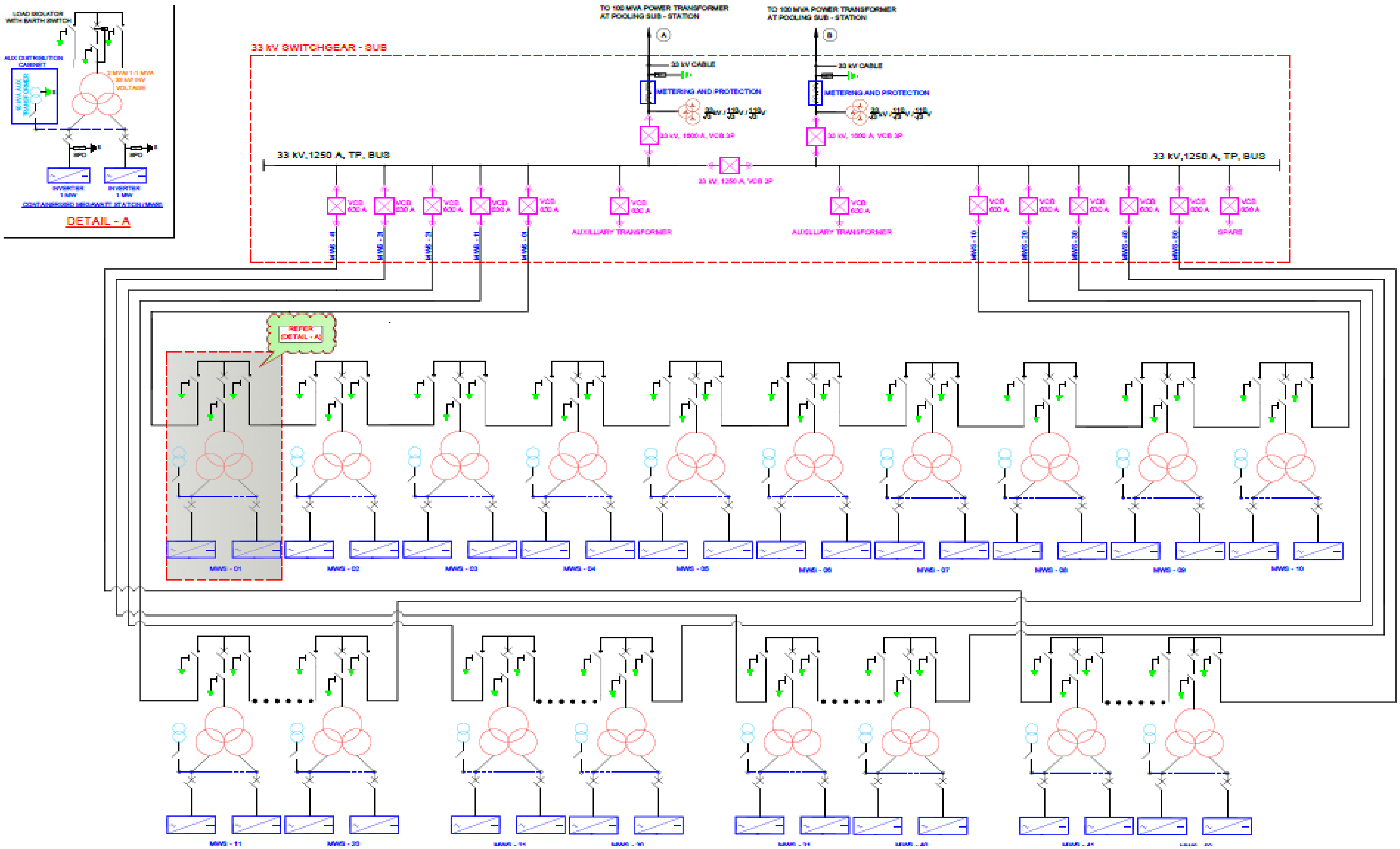
The various power evacuation and interconnection options are given in chapter 2 and here we would briefly discuss the final selection and basic layout of a 33/ 230 kV pooling SS from which dedicated transmission lines would be evacuating the power to the PGCB network.

Following images show the SLD of the pooling SS for this RE project:

Figure 43: *SLD of power evacuation*



Source: *PGCB*


33 kV SWITCHGEAR - SUB
TO 100 MVA POWER TRANSFORMER AT POOLING SUB - STATION
TO 100 MVA POWER TRANSFORMER AT POOLING SUB - STATION
33 kV CABLE
METERING AND PROTECTION
33 kV,1250 A, TP, BUS
33 kV,1250 A, TP, BUS
AUXILLIARY TRANSFORMER
AUXILLIARY TRANSFORMER
SPARE
DETAIL - A
REFER (DETAIL - A)

Source: *PGCB*

Note: For better legibility the PDF file of the SLD shall be shared separately.

The bill of quantity (BOQ) of the above shown 200 MWac pooling SS layout is attached below (considering power evacuation of both Phases to 230 kV Mirsarai grid GSS):

Table 39: *BOQs of 200 MWac power evacuation in recommended option 7*

S.No.	Description	Unit
1	**33 kV Sub Switchgear (Indoor Type)**	1 No.
	33 kV, 1250A Bus, 3-Phase Switchgear comprising of 13 Nos of 630 A VCBs and 2 Nos of 1600 A VCBs and 1 No. 1250 A VCB along with associated Instrument Transformers (CTs / PTs), Meters, Protective Relays, LAs, etc.	
2	**33 kV Main Switchgear (Indoor Type)/Pooling Sub Station**	1 No.
	33 kV, 2500A Bus, 3-Phase Switchgear comprising of 13 Nos of 630 A VCBs and 2 Nos of 1600 A VCBs and 3 No. 2500 A VCB along with associated Instrument Transformers (CTs / PTs), Meters, Protective Relays, LAs, etc.	
3	**33 kV Cables**	
	33 kV Solar Ring Main System (100 MW) to 33 kV Sub Switchgear and 33 kV Solar Ring Main System (100 MW) to 33 kV Main Switchgear (Pooling Substation)	119 km
	33 kV Cable from Sub Switchgear to 33 KV Main switchgear (Pooling Substation)	
	33 KV Main switchgear (Pooling Substation) to Transformer	
4	**33 kV / 230 kV Switchyard**	
	100 MVA, 230 kV / 33 kV, ONAN/ONAF Power Transformers	2 Nos.
	50 kVA, 33 kV / 0.415 kV, Auxiliary Transformers	4 Nos.
	230 kV Feeder Bay comprising of 1250 A, SF6 Outdoor type breaker, Motorised Double Break Isolator, LA, CTs, Metering & Protection, etc.	2 Bays
	230 kV Outgoing Bay comprising of 1600 A, SF6 Outdoor type breaker, Motorised Double Break Isolators, Earth Switch, LA, CTs, PTs, Metering & Protection, ABT Meters, etc.	2 Bays
	230 kV Bus-PT Bay comprising of Motorised Double Break Isolator.	2 Bay

	230 kV Bus Coupler Bay comprising of 2500 A, SF6 Outdoor type breaker, Motorised Double Break Isolator, LA, CTs, Metering & Protection, etc.	1 Bay
	230 kV Bus Transfer Bay comprising of 1600 A, SF6 Outdoor type breaker, Motorised Double Break Isolator, LA, CTs, Metering & Protection, etc.	1 Bay
5	**Transmission Line**	
	A 230 kV Double Circuit Transmission Line with Moose Conductor to Mirsarai SS	20 km
Note: Tentative BOQ from Inverter AC side 33kV to Transmission Line		

The technical specifications for the cables, conductors and relay settings for the project will be designed as per Bangladesh grid code by the developer and the schemes and BOQ given here is an indicative document only.

Following table shows results of the analysis for power evacuation of both phases in recommended option 7:

Table 40: *Power evacuation capacity and cost of recommended option 7 in both phases*

Parameter	Unit	Phase-1	Phase-2
		Solar PV	Balance Solar PV
Capacity	MWdc	68	204
	MWac	50	150
	Total MWac	**50**	**150**
Evacuation items		Two 100/125 MVA, 230 kV / 33 kV, ONAN/ONAF Power Transformers; 2 transformer feeder bays + 2 outgoing transmission line bays + 2 bus PT bays + 1 bus coupler + 1 bus transfer bay; 230 kV two circuit transmission line of around 20 KMs; two additional bays at 230 kV grid SS; 33 kV Sub Switch gear Indoor type VCBs (13 X 630 A + 1 X 1250 A + 2 X 1600 A; total 16 numbers); 33 kV main switch gear indoor type pooling SS (13 X 630 A + 3 X 2500 A + 2 X 1600 A; total 18 numbers)	
Total evacuation cost	million USD	**6.621**	

6.2 Power Off-take Options

As a legal contract between the plant operator and the purchaser of the electricity produced (off-taker), a Power Purchase Agreement (PPA) defines future project revenues. Hence a PPA will be signed between project owner and off-taker.

In this case, power off-taker will be BPDB, who will buy the power from this project through duly defined and specified PPA as per applicable acts and rules of Bangladesh.

The off-take conditions (voltage, tariff, etc.) will be in-line with the Grid Code and Distribution Code of Bangladesh Energy Regulatory Commission (BERC).

As per BERC followings are requirements' overview for grid connectivity:

- General requirements
  - Application for Connection
  - Site responsibility Schedule
  - Connection Voltage
  - Maintenance Responsibility
  - Data Requirement
- System Performance
  - Generator : 47.5 – 52 Hz, PF 0.8 lag to 0.95 lead
  - Grid Frequency : 49 - 51 Hz
  - Voltage : ± 5% normal ± 10% emergency
- System Design Short Circuit Level – 12123 MVA (3-Phase)
- International and Regional Connection
  - Synchronous or Asynchronous
  - HDVC Connection and Back to Back (B2B) Interface
- Fault Clearing Time
  - 400 kV : 100 ms
  - 230 kV and 132 kV : 160 ms

The grid code, controlled by the grid operator i.e. PGCB, specifies how a generating plant must connect to and interface with the electricity distribution network. The PPA should reference the grid code and clearly specify how compliance with that code is determined as a condition for commercial operation. There may be room to negotiate relaxation of grid code requirements for solar projects if specific code for renewables has not yet been adopted. If the grid code has not been updated to cover intermittent energy sources, such as solar, certain provisions may need to be included in the PPA.

Considering the limited funding pool available with the federal republic of Bangladesh and in view of maximising the benefits of the grant money from World Bank group, the best option for power intake can be a mixture of the following options.

1. EGCB can start with outright ownership as an anchor agency for 50 MWac solar PV capacities in Phase-1 with equity support from domestic/ foreign lending agencies and debt from World Bank group. EGCB will also act as overall park developer making investments in developing the total shared infrastructure like land development, pooling sub-station development and putting in place approvals related to grid tie-up and other statutory clearances.

2. The balance solar PV and wind capacity in Phase-2 are bounded out in IPP mode with bidders invited to bid on a tariff-based reverse bidding mode. Bidders have to bid considering the cost of shared services like land, power evacuation and other common infra like CMCS. Roads and telecom infra has already been made ready at the site by EGCB and just need to incorporate the apportioned cost of these shared services on a per MW basis. The bidders for the allocated capacity will be entering into long-term Power Purchase Agreement (PPA) with EGCB. EGCB will be providing them payment guarantee in the form of a rolling bank guarantee against three months estimated billing. The tariff will be set for a guaranteed number of units and any shortfall in delivered units due to technical issues related to the performance of the solar PV components installed by the integrated power producer (IPP) will be compensated by the IPP to EGCB at the agreed tariff level. For any shortfall in delivering power to EGCB from IPP due to grid shutdown and interference from the installed solar PV and wind systems installed by EGCB (causing revenue loss due to conditions beyond the control of the IPP) then, in that case it will be considered as deemed generation and the IPP will be compensated by EGCB and PGCB. Guaranteed deemed generation system has been successfully implemented in India with World Bank group funding and we feel payment guarantee for deemed generation loss will provide ample incentive to the developers to attract them to invest in this first multi-megawatt grid connected solar and wind power project in Bangladesh.

3. Another option can be a public private partnership (PPP) mode, where EGCB and PGCB can invite bids for development of the entire capacity of the renewable energy project based on reverse bidding model, and the winner(s) will be forming a special purpose vehicle (SPV) with EGCB and PGCB for operating this asset for 25 years. As part of their equity contributions for the project, EGCB can provide land and power evacuation infra, grid tie-up approval and common infrastructure facilities.

Hence the developer can develop the solar PV and wind capacity in a BOOT model with the entire infrastructure transferred to the EGCB after 25 years. This will provide the developer opportunity to raise cheap international debt for the project based on very limited power off-take risk. This will bring down the WACC of the overall project and also give the developer additional negotiating power with international Tier-1 module and inverter manufacturers. Often these Module manufacturers will bring favourable debt financing options based on the volume (130MWp+) of modules and also based on the payment risk mitigation provided by the SPV with the federal utility as a shareholder.

4. Based on the response of the bids received, EGCB can also decide to invite pure-play EPC contractors for setting up the project on a cost plus basis indexing. Similar EPC project experience is there in India where World Bank has been involved as a funder for state owned entities like Solar Energy Corporation of India (SECI). This option can be exercised only if EGCB and World Bank feel there is a case for substantial reduction of cost of the project and the LCOE, if EGCB develop this project as their flagship and tariff quoted by IPP in the reverse auction is highly ambitious in terms of profit expectations.

6.3 Project development

This study has presented two phases of development of this project, in Phase-1 solar PV of 50 MWac capacity will be executed and remaining solar PV i.e. 150 MWac solar PV capacity will be executed in Phase-2. Following table shows the proposed phasing for the recommended Option 7:

Table 41: *Project development phasing for recommended option*

Parameter	Unit	Phase-1	Phase-2	Remark
		Solar PV	Balance Solar PV	
Capacity	**MWdc**	68	204	Land leveling, associated dike & infrastructure work, Pooling SS and Approach Road will be developed. For Financial analysis associated costs have been proportionately divided into two phases.
	MWac	50	150	
	Total MWac	200		

Model	**-**	EPC, with 5 years O&M	BOOT model	Phase-2: Tariff discovered through bidding.
Ownership	**-**	EGCB	IPP/PPP	
Power sale	**-**	BPDB	BPDB	
Expected date of commissioning	**-**	Apr-19	Apr-20	

CHAPTER - 7

FINANCIAL ANALYSIS

7.1 Financing cost & assumptions

With a financial model adapted to Bangladesh, the effects of the defined assumptions will be calculated to provide an economic basis for the conclusions of this report. The key input parameters for the financial model are, among others:

- Estimated annual electricity yield given in MWh per year (based on site-specific solar irradiation and technical configuration)
- Investment cost (CAPEX)
- Operation and maintenance cost (OPEX)

as well as the assumptions regarding the financing scheme. Standard formulas are used to perform the calculations considering these assumptions.

The financial model uses a single currency (here: USD) and is based on a yearly cash flow, where revenues and costs are calculated according to the assumptions and technical input of the project configuration. For the calculation of key performance indicators (such as Net Present Value (NPV) of the project, the Equity Internal Rate of Return (IRR), or alternatively the tariff in USD/MWh) the financial modelling takes into account the income statement, the balance sheet and the cash flow statement.

The financial parameters for the calculations are shown in the table below:

Table 42: *Financing assumptions (Phase-1)*

S. No.	Key Assumptions	Unit of measurement	Value	Source
1	Leverage (Debt/Eq)	-	70/30	Assumption based on similar projects
2	Min DSCR	-	1.2	
3	Tenor (years)	Years	20	Reflecting concessional loans currently available with EGCB
4	Interest Rate	%	4	Reflecting concessional loans currently available with EGCB as confirmed by EGCB
7	DSRA	Months	0	
8	Targeted Equity IRR	%	15	EGCB Inputs; Close to private sector estimates using Risk Free rate (Govt Bond date) + 8% ~ 16%.

On the basis of the above mentioned financing assumptions and technical parameters, the Consultant calculated the LCOE of the solar PV for the recommended option and other options.

The Consultant is aware that there are currently no local banks capable to finance an utility scale solar project in Bangladesh. The ideas on how to enable local financing for solar project are going to be explored separately in Task 5. Thus, the Consultant only considers the **IFC financing** for the technical calculations at this stage of the Feasibility Study. For Phase 2 IPP mode, the following preliminary financial assumptions have been taken into account**.**

Table 43: *Financing assumptions (Phase 2)*

S. No.	Key Assumptions	Unit of measurement	Value	Source
1	Leverage	-	70/30	Assumption based on similar projects
2	Min DSCR	-	1.2	
3	Tenor (years)	years	12	Based on discussions WB, EGCB, Finance experts in Bangladesh for private players
4	Interest Rate	%	12	Discussion with local finance experts; Govt Bond Rate (20 yrs) ~ 8.07%+4% ~ 12%.
5	Up-front fee	%	0.5	Anecdotal- based on discussions WB, EGCB, others
7	DSRA	Months	6	Assumed based on prevalent practice in other Asian countries
8	Targeted Equity IRR	%	16	Risk Free Rate (Government Bond Rate)~8.07% + 8% risk premium

Following table shows the assumed tax rates for the financial analysis:

Table 44: *Tax Rate Assumptions*

S. No.	Key Assumptions	Unit of measurement	Value	Source
1	Corporate Tax rate	%	35%	Applicable to private companies in Bangladesh
2	Depreciation	%	3.80%	Based on assumption of asset depreciation rate by

				Straight line method depreciation (SLM) over asset life leaving 5% salvage value
3	Tax holiday	Years	15	Incentives available under private power generation policy of Bangladesh, 2004 for winning developers of tenders bid out by Powercell. No restriction could be found in this policy for restricting only to coal/fossil fuel, thus assumed to be available for this project as well. Assumed to apply from commissioning.
4	Minimum Tax	% of gross revenue	0.60%	as per finance act 2016
5	Loss carry forward	# years	6	As per publicly available information

7.2 Financial analysis of Solar PV Plant

7.2.1 Capital expenditures (CAPEX) – Solar PV plant

The CAPEX comprise all costs for the installation of the plant, including civil structures and interconnection to the closest substation. For solar PV installations, the major driving factor of capital expenditures is the cost of solar PV panels. In the past years, solar panel prices have represented approximately 40% to 50% of total solar PV system installed, price depending on the market and application type.

The following three key components of the CAPEX shall be explained in more detail:

1. EPC cost
2. Owner's cost
3. Financing cost

7.2.1.1 EPC cost

For a non-recourse project financing scheme, a so-called EPC contract is mostly mandatory to integrate the construction risk and allocate to a party that can manage it. As such, in case of an EPC turnkey project, an experienced EPC contractor will carry out the engineering for the project, procure all the equipment and materials necessary and construct the plant, thus, providing the owner a facility that is "ready to use". The EPC contractor has to execute and deliver the project within an agreed time and budget, commonly known as a fixed-price, Date Certain Turn Key contract, providing the owner (or the Special Purpose Company) the respective guarantees.

EPC cost consists of the cost of plant equipment, on-site facilities and all infrastructure supporting the plant installation (e.g. workshops, office and roads) as well as cost for the direct and indirect labour required for the construction of the plant. These costs are often summarized as “bare erected costs”. Further, there is the cost of services provided by the EPC contractor, including the basic and detail engineering, contractor permitting, project and construction management, site related studies, commissioning and start-up services or other indirect costs. Last, the EPC cost includes the profit margin of the contractor and his contingencies.

7.2.1.2 Owner’s cost

The owner’s cost includes all further expenses for the owner, which are not included in the EPC turnkey package and which are not related to the financing of the project. The owner’s cost can be grouped into the following:

- Project development (incl. preparatory studies and surveys, permits and licensing, taxes, development fee etc.)
- Land cost (purchase or land lease during construction)
- Additional owner’s cost (owner's management, owner's engineering, advisory services, lender's technical, legal and insurance advisors, insurances, O&M mobilization, pre-operating costs and contingencies etc.)

7.2.1.3 Financing cost

The financing costs prior to the commercial operation date depend on the financing structure of the project. In the case of debt financing, the fees related with the negotiation and closing of the financial agreements may include appraisal fee, up-front fee (also arranging fee and structuring fee) and syndication fee (if applicable).

Other financing costs are the commitment fee (payable on the committed but not yet disbursed loan amount), interest during construction (IDC), and funding of the debt service reserve account (DSRA) with equity or with a letter of credit facility.

The following table shows the CAPEX assumptions for the solar PV recommended option:

Table 45: CAPEX assumptions for PV plant recommended Option 7

Description	Option 7 (CAPEX)			
	Phase 1: 50 MW_{AC} (68 MW_{DC})		Phase 2: 150 MW_{AC} (204 MW_{DC})	
	USD/MW_P	Million USD	USD/MW_P	Million USD
Solar PV Modules	329600	22.43	312500	63.79
Mounting systems (fixed-tilt)	117634	8.00	116530	23.79
Inverter + Transformer stations	77500	5.27	73876	15.08
Combiner boxes, DC/AC cables	19366	1.32	18685	3.81
Electrical installation (mounting, earthworks and cable laying, medium voltage, SCADA)	76220	5.19	71390	14.57
Civil works (buildings, roads, site preparation, security)	21980	1.50	20587	4.20
Other (site facilities, engineering, experts, logistics, services, margin, miscellaneous)	73160	4.98	68338	13.95
Emerging market factor	10%	4.87	10%	13.92
Dike construction cost	-	10.77	-	11.58
Cost for pumping system	-	0.32	-	0.75
Power Evacuation Cost	-	1.66	-	4.97
Site Approach road	-	0.07	-	0.22
Total Cost		**66.37**		**170.63**
Cost for land lease	55540	3.67	44445	11.03
Development cost (including fees)	-	4.00	-	3.00
Financing cost	-	0.60	-	4.40
Working Capital	-	0.36	-	0.91
Total Investment Cost (TIC)	**-**	**75.00**	**-**	**189.97**

It should be noted, that the complete infrastructural cost associated with the access road, grid connection, flood protection measures such as the dike and pumping system as well as land acquisition cost are allocated to PV technology within the LCOE calculations.

7.2.2 Operation and maintenance expenditures (OPEX) – solar PV plant

The OPEX are the fixed and variable O&M costs, which include the following:

- Monitoring (reporting, failure management)
- Corrective maintenance
- Preventive maintenance
- Special inspections all 4 years
- O&M staff
- PV module cleaning
- Site maintenance / vegetation management
- Commercial plant management
- Accruals

The day-to-day operation and maintenance of a solar PV plant is conducted by an experienced O&M contractor, which guarantees his services at a fixed price. The assumed O&M cost do not include the insurance for the plant.

Table 46: OPEX assumptions for solar PV plant recommended Option 7

Description	Option 7 (OPEX)			
	Phase 1: 50 MW_{AC} (68 MW_{DC})		Phase 2: 150 MW_{AC} (204 MW_{DC})	
Annual OPEX	**USD/MW_P**	**Million USD**	**USD/MW_P**	**Million USD**
O&M cost in conventional system	13805	0.94	12174	2.48
O&M cost in robotic automatic dry type system	22500	1.53	22500	4.59

O&M cost breakdown	Option 7 (m USD)	
	Phase 1	Phase 2
Monitoring (Reporting, Error-Analysis & -Management)	0.11	0.28
Preventative Maintenance	0.15	0.38
Corrective Maintenance (Repair)	0.11	0.30

Special inspection all 4 years (cost applicable on an annual basis)	0.05	0.13
Site Maintenance / Vegetation Management	0.07	0.18
Module Cleaning (assumption: 4 times per year)	0.07	0.19
Commercial Plant Management	0.07	0.13
Accruals	0.26	0.72
miscellaneous/contingencies	0.05	0.16
Total	**0.94**	**2.48**

Considering site location and salinity of the site being coastal area, automatic dry type robotic module cleaning can be an option. However we have used cost of conventional O&M for financial analysis. Further choosing O&M method is open with client.

Note: *For further details on robotic system refer section 5.5 of this FSR.*

7.2.3 Risk analysis – solar PV plant

In a solar project financing scheme it is essential to diligently analyse and evaluate potential risks. Once certain risks are identified and considered, the appropriate measures to mitigate them can be adopted. In the context of this chapter, risk shall be deemed as the negative deviation of a factor from a targeted value. In a project financing, particularly those factors influencing the cash flow are of great significance.

There are different approaches for risk breakdown models. In order to cluster the risks according to their type, we can outline the following categories:

1. Construction Risks
    a. Cost overrun
    b. Time overrun
    c. Technical performance
2. Market and Operational Risks
    a. Sales and revenue risk
    b. Energy yield risk – solar resource risk
    c. Operative risk
    d. Competition risk

3. Financial and Credit Risks
    a. Interest rate risk
    b. Foreign exchange rate risk (FX risk)
    c. Inflation risk
4. Political Risks
    a. Expropriation
    b. Change in law
    c. Convertibility risk
5. Force Majeure Risk
    a. Floods
    b. Hail storms

These five clusters describe the main risk categories and usually in a project financing, they have multiple subgroups and sub-risks that need to be evaluated and allocated in the project agreements. Also, they need insurance agreements and project financing contracts in order to avoid any risk event that would be fatal to the project. Most risks can be analysed in the financial model. A reduction of revenues from a construction failure, malfunctioning equipment or an overestimation of solar irradiation, for instance, can be tested in the financial model and the effect on cash flow, debt and equity can be estimated. Other risks have a rather binary impact, such as an expropriation of the project (nationalization) that takes away all property rights and fully transfers ownership and operation. A similar effect occurs if a national off-taker is being advised by the government not to pay its dues under the PPA contract. Another risk would be a change in the interest rate during the lifetime of the loan. In order to see how most of the mentioned risks would typically be addressed and allocated, the Consultant uses a risk matrix to show a typical risk analysis and structure (see Appendix D).

7.2.3.1 Completion risk – solar PV plant

The completion risk can occur through a cost overrun in construction, a time overrun, by not achieving completion at all, or by the completed plant not meeting pre-defined performance levels. The assessment is made by increments in different CAPEX elements and their impacts on the results of the project.

7.2.3.2 Operational and Management risk – solar PV plant

All threats during the operating phase that disrupt the production or lead to higher operational costs can be pooled as operational and management risks. Causes for an operational and management risk include poor planning, organization or execution of operational procedures. Hence, the experience of the management personnel is crucial. Possible limitations of production have a negative impact on the output quantity and consequently on generated income. The key consequence in the model is a lower cash flow, i.e. revenues.

7.2.3.3 Functional risk – solar PV plant

The functional risk includes risks such as lower quantity or problem with reaching the quality of the product due to immature technologies, or un-developing production methods. Due to substantially lower revenues, the ability of the project to serve its debt obligations can be jeopardized.

7.2.3.4 Resource risk – solar PV plant

In case of a solar power project, the resource risk can be described by the threat that solar irradiation (the resource) does not correspond to the initial assumptions. If less solar irradiation is available this may cause lower income possibly during the entire project lifetime, thus, this is an extremely sensitive risk aspect. Solar resource assessment and energy yield estimation can provide a high degree of certainty. Risk in solar resources may lead banks and sponsors to invest in additional equipment in order to boost energy yield.

7.2.3.5 Financial risk – solar PV plant

The financial risk includes the interest rate risk, the inflation risk and the exchange rate risk. An increase of the interest rate can decrease the project return by a significant percentage. Since interest rates are quite sensitive to project economics it is highly recommended to hedge the interest rate over the lifetime of the loan, as usually done in best practice project financing. This can be implemented by either lenders providing fixed interest rates or by the SPV buying interest rate hedging instruments like SWAPs for floating interest rate loan e.g. LIBOR basis.

7.2.4 Levelised Tariff of recommended Option 7

For the LCOE calculation, the impacts of inflation (on the tariff, O&M and other costs), as well as tax and depreciation, have been taken into account. The financial model is tuned as to realise a fixed internal rate of return of 15%. The financial model considers a stream of cash flows throughout the lifetime of the entire project from today's point of view. The resulting tariff provides the LCOE, expressed in USD/kWh. This is a different approach compared, for instance, to SAM (System Advisor Model) from the American

National Renewable Energy Laboratory, which uses the equation of total project costs and total generation in kWh, subject to a discount rate.

The applied financial model represents international best practice and has been used for different projects across different countries and technologies (CSP and PV).

Following figure shows the LCOE of solar PV in recommended Option 7:

Figure 44: *LCOE of solar PV in recommended option for Phase 1 and Phase 2*

Financial Assumptions Phase 1 / Phase 2:

1. Leverage debt / equity = 70 : 30 ratio
2. Equity IRR =15 %
3. DSCR = 1.2Times
4. Tenure = 20 / 12 Years
5. Interest Rate (base rate plus margin) = 4 / 12 %
6. DSRA = 0 / 6 Months
7. CAPEX = 66.37 / 170.63m USD
8. OPEX = 0.94 /2.48m USD

Technical Assumptions (Phase 1 / Phase 2):

1. Capacity = 50 / 150 MWac (68 / 204 MWdc)
2. Fixed-tilt system with polycrystalline module
3. Central Inverters: SMA inverter station MVPS-2000SC4. PLF = 17%
5. Probability = P75
6. AEP = 98.12/ 294.32 GWh/yr (net)

LCOE = 10.18 / 9.99 USD cents/ kWhr

Source: *WFMS*

7.3 Financial Analysis of Wind farm

This project will have the first commercial scale megawatt level grid-connected commercial wind power project in Bangladesh. Since there are no benchmark or reference capital cost for projects in Bangladesh, the Consultant has to assume costs as prevalent in Indian markets since India has now the 4th largest cumulative wind power installation in the world at 32 GW and all major international wind power equipments manufacturers like GE Wind, Vestas, Gamesa, Senvion along with domestic majors like Suzlon and Inox have a robust manufacturing presence in India and are supplying equipments to all neighbouring countries. Also the wind profile of many sites in India is similar to the site at Sonagazi and we can take Indian capital costs and indexing them considering cost of cement, steel and labour cost in Bangladesh.

Prima facie, the major difference in capital cost will be occurring in the balance of system components like cement, steel, sand and also hiring charges for large-sized high capacity crawler cranes which are available in limited numbers and have very high mobilisation and rental costs. Also there would be considerable cost in hiring expert manpower for wind turbine erection, commissioning and operation and maintenance in the initial stages of the project. Such expert manpower need to be initially hired from outside Bangladesh during the project planning and implementation stage and their cost will increase the overall CAPEX by a margin of 1.5-3.00 percentage points .

7.3.1 Financing cost & assumptions – Wind farm

With a financial model adapted to Bangladesh, the effects of the defined assumptions will be calculated to provide an economic basis for the conclusions of this report. The key input parameters for the financial model are, among others:

- Estimated annual electricity yield given in MWh per year (based on site-specific solar irradiation and technical configuration)
- Investment cost (CAPEX)
- Operation and maintenance cost (OPEX)

as well as the assumptions regarding the financing scheme. Standard formulas are used to perform the calculations considering these assumptions.

The financial model uses a single currency (here: USD) and is based on a yearly cash flow, where revenues and costs are calculated according to the assumptions and technical input of the project configuration. For the calculation of key performance indicators (such as Net Present Value (NPV) of the project, the Equity Internal Rate of Return (IRR), or alternatively the tariff in USD/MWh) the financial modelling takes into account the income statement, the balance sheet and the cash flow statement.

The financial parameters for the calculations are shown in the table below:

Table 47: *Financial parameters for wind project*

Assumptions	Worst Case
Leverage	70/30
Required DSCR	1.2x
Tenor (years)	12
Interest Rate	10%
Up-front fee	0%
Commitment fee	0%
DSRA (mths)	6
Interest on DSRA	1.0%

7.3.2 Capital Expenditures (CAPEX) – Wind farm

The CAPEX comprise all costs for procurement, delivery and installation of all major and minor components that are part of the plant design, including civil structures, electrical line and interconnection to the closest electrical substation.

For wind turbine project installations, the major driving factor of capital expenditure is the wind turbine generator understood as the combination of blades, nacelle and tower. In the past years, turbine prices have remained steady with minor increase in the prices due to increase in input costs of metals like steel and copper.

The following three key components of the CAPEX shall be explained in more detail:

1. EPC cost

2. Owner's costs
3. Financing cost

7.3.2.1 EPC cost

For a non-recourse project financing scheme, a so-called EPC contract is mostly mandatory to integrate the construction risk and allocate to a party that can manage it. As such, in case of an EPC turnkey project, an experienced EPC contractor will carry out the engineering for the project, procure all the equipment and materials necessary and construct the plant, thus, providing the owner with a facility that is "ready to use". The EPC contractor has to execute and deliver the project within an agreed time and budget, commonly known as a fixed-price, Date Certain Turn Key contract, providing the owner (or the Special Purpose Company) with the respective guarantees.

EPC costs consist of the costs for plant equipment, on-site facilities and all infrastructure supporting the plant installation (e.g. workshops, offices and roads), as well as costs for the direct and indirect labour required for the construction of the plant. These costs are often summarized as "bare erected costs". Further, there are the costs of services provided by the EPC contractor, including the basic and detail engineering, contractor permitting, project and construction management, site related studies, commissioning and start-up services or other indirect costs. Last, the EPC costs include the profit margin of the contractor and his contingencies.

7.3.2.2 Owner's costs

The owner's costs include all further expenses for the owner, which are not included in the EPC turnkey package and which are not related to the financing of the project. The owner's costs can be grouped into the following:

- Project development (incl. preparatory studies and surveys, permits and licensing, taxes and development fee etc.)
- Land costs (purchase or land lease during construction)
- Additional owner's costs (owner's management, owner's engineering, advisory services, lender's technical, legal and insurance advisors, insurances, O&M mobilization, pre-operating costs and contingencies etc.)

In most cases of large wind power projects in Asia, equipments manufacturers like Gamesa, Vestas, Senvion, Regen Powertech, Suzlon, Inox usually undertake the entire EPC including development cost as a turn-key project, thereby guarantying timely execution, quality control and adherence to design. In the Asian context, except large well-established IPP and developers, companies rarely contract supply and work of the entire project separately, especially for wind power projects. In light of this trend in

Asia and considering the fact that there has not been any large-scale development of wind power projects in Bangladesh, it is foreseen that developers/ IPP will favour turn-key solutions especially for the first large-scale project, where construction and design risks outweigh other factors.

7.3.1.3 Financing costs

The financing costs prior to the commercial operation date depend on the financing structure of the project. In the case of debt financing, the fees related with the negotiation and closing of the financial agreements may include appraisal fee, up-front fee (also arranging fee and structuring fee) and syndication fee (if applicable).

Other financing costs are the commitment fee (payable on the committed but not yet disbursed loan amount), interest during construction (IDC), and funding of the debt service reserve account (DSRA) with equity or with a letter of credit facility.

Often in the Asian context it is noticed that large wind equipments manufacturers have arrangements with financial institutions and that they offer financing options linked to supply and performance of their works and the long-term performance of the projects. This reduces the risk of performance uncertainty for the project since financers are comfortable with the technicalities of the projects and can control risks better than a less experienced financial institution which might not be comfortable lending to a new industry.

Following table shows the CAPEX cost of wind farm of 10 MWac capacity:

Table 48: *CAPEX assumptions for wind farm (10 MWac)*

Description	Unit Price (USD)	Cost of EPC
EPC / Investment for PV Power Plant	**USD/MW**	**million USD**
Wind Turbine generator	900000	9
BOP- Civil	100000	4
Electrical DP yard	100000	4
BOP- Electrical items – 33 KV lines	100000	4
Erection , Commissioning costs	100000	4
Total EPC cost – wind project / MW	**1300000**	**25**

Power Evacuation Cost (excluding 33 kV single circuit transmission line)		**0.47**
Working Capital Margin	**-**	0.13
Financing cost	-	0.12
IDC + Commitment Fee	-	0.16
Total Investment Cost (TIC)	**-**	**25.88**

7.3.3 Operation and maintenance expenditures (OPEX) – Wind farm

Taking the indexed cost of a similar sized project using similar equipments and operating on a pure IPP mode, the annual OPEX for wind farm are estimated at 20000-22000 USD/MW/a. This is usually a comprehensive operation and maintenance price considering zero liabilities for any breakdown related cost for the project owner. The comprehensive OMS is provided by the OEM who usually acts as EPC contractor for the project. Considering the higher cost due to lower volumes for one project and the associated cost of storing all major components like blades, generators and transformers at site, the cost of OMS can be taken as USD 20000/ MW/ Year.

Following tables shows the cost of OMS:

Table 49: *OMS cost of 10 MW wind farm*

Comprehensive OMS Cost in USD/MW/annum	Total Cost of OMS (10 MW) – m USD/annum
20000-22000	0.2 – 0.22

The other costs associated with the project are

A. Insurance cost – the cost of insurance on a MW basis per annum considering reinstatement clause premium is estimated at 2000 USD/MW/a.
B. Cost incurred in statutory dues like land tax, local panchayat tax, sales tax for maintaining office and apportioned cost of head office staffs engaged in asset management.
C. Cost of travel, contingency, telecommunication and transportation assets and local guest houses etc.

7.3.4 Risk analysis – Wind farm

7.3.4.1 Completion risk-

One of the main risks associated with wind power projects is the risk of abandonment of the project due to the local law and order situation, flooding of the site and bankruptcy of the project execution agency. Other factors like changing political and legal frameworks could also jeopardise the project. Further, the execution can be stopped on grounds of violation of environmental laws, labour laws and safety regulations.

7.3.4.2 Operational and Management risks

The main risk related to the wind power project is a shutdown and/or short-circuits due to an unforeseen flooding of the site caused by storms and tidal surge of the Feni river. This risk can be mitigated by building a dyke at the southern side of the site towards the river bank. This would prevent sudden uncontrolled water ingress into the site and also give the maintenance team enough time to take emergency flood control measures like putting-up temporary dykes using sand bags and using high-capacity pumps to remove water from the plant area. Though the DP yard may be elevated 5 m above the ground using the design demonstrated earlier, the cable trenches may get exposed to water.

7.3.4.3 Functional risk-

The other risk arises due to malfunctioning of the installed wind turbine generators due to damage in transit, unsafe operation caused by grid fluctuations, cyclonic winds damaging blades, or a lack of generation due to inherent design flaws and defects in the equipment installed. Some of the defects are covered by guarantees of the OEM and respective clauses protect against financial losses but for other risks, the project may have to stop operating pending complete replacement.

7.3.4.4 Resource risk-

Wind resource assessment is currently being conducted at the site and in case the WRA is not comprehensive and equipments used are not matched against the available wind resource at site, the project will stop operating completely. There have been numerous cases of equipment and wind resource mis-match in India and even in Bangladesh leading to total non-performance of the asset.

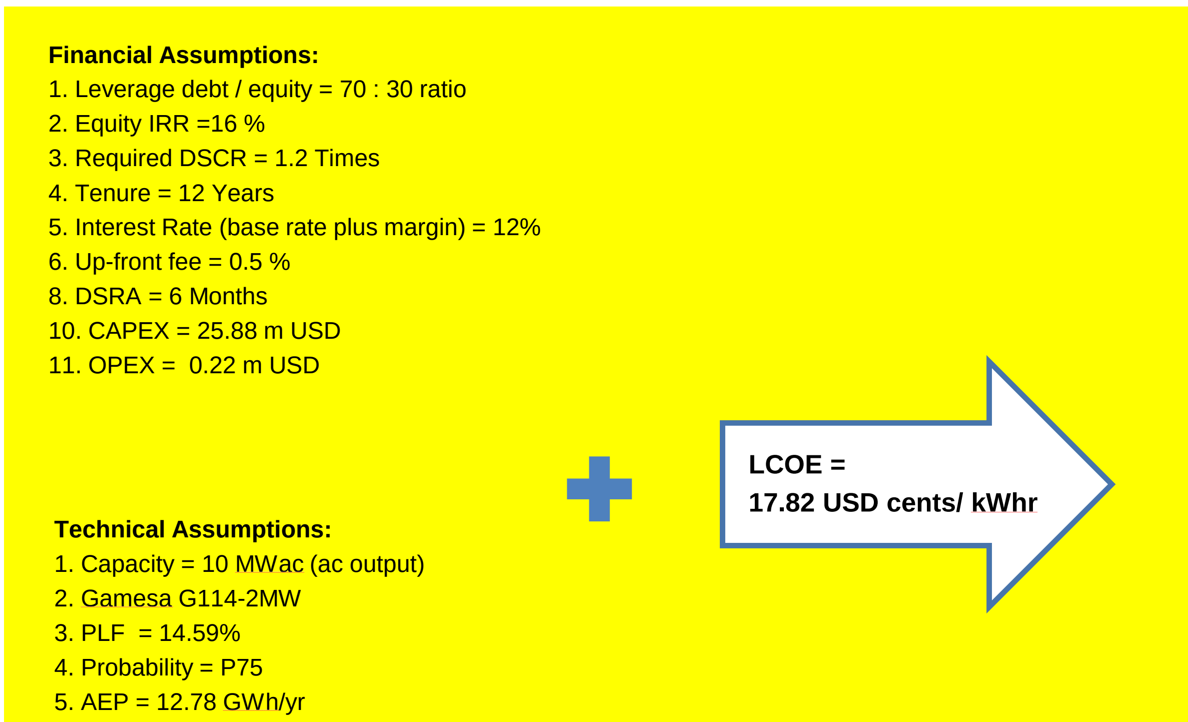
7.3.4.5 Financial risk-

The main financial risk of the project is due to non-performance of the asset, thereby not allowing the IPP / Developer to accrue revenue to pay the debt + interest portion of the loan.

7.3.5 Levelised Tariff of wind farm:

Following figure shows the LCOE of 10 MWac wind power system

Figure 45: *LCOE of 10 MWac wind power project*



Source: *WFMS*

7.4 Financial feasibility of the recommended option 7

Based on the assessment, site suitability & requirements one Option out of all assessed options has been recommended for the site i.e. Option 7- only 200 MWac solar PV with no wind this recommended option shall have around 25% of total land area for livelihood activity in distinct manner e.g. Intensive Fishery.

Following table shows the summary of financial analysis of the recommended option 7 in two phases:

Table 50: *LCOE of the project in phasing for recommended option 7 (P75)*

Option 7 (in two Phases)			
Parameter	Unit	Phase-1	Phase-2
		Solar PV	Solar PV
Technology		Fixed-tilt solar PV system based on central inverter and polycrystalline module technology	
Capacity	MWdc	68	204
	MWac	50	150
	Total MWac	200	
Net Energy Yield	GWhr/yr	99.42	298.25
Total Area	Ha	67.3	201.85
CAPEX	m USD	66.37	170.63
OPEX	m USD	0.94	2.48
LCOE	USD cents / kWh	10.18	9.99

Note: *The cost of road, elevated structure, diking, pumping, pooling SS is included in this analysis. The calculated cost of Diking for the entire project area (10.8 km) for recommended Option 7 is 21.5 m USD.*

CHAPTER - 8

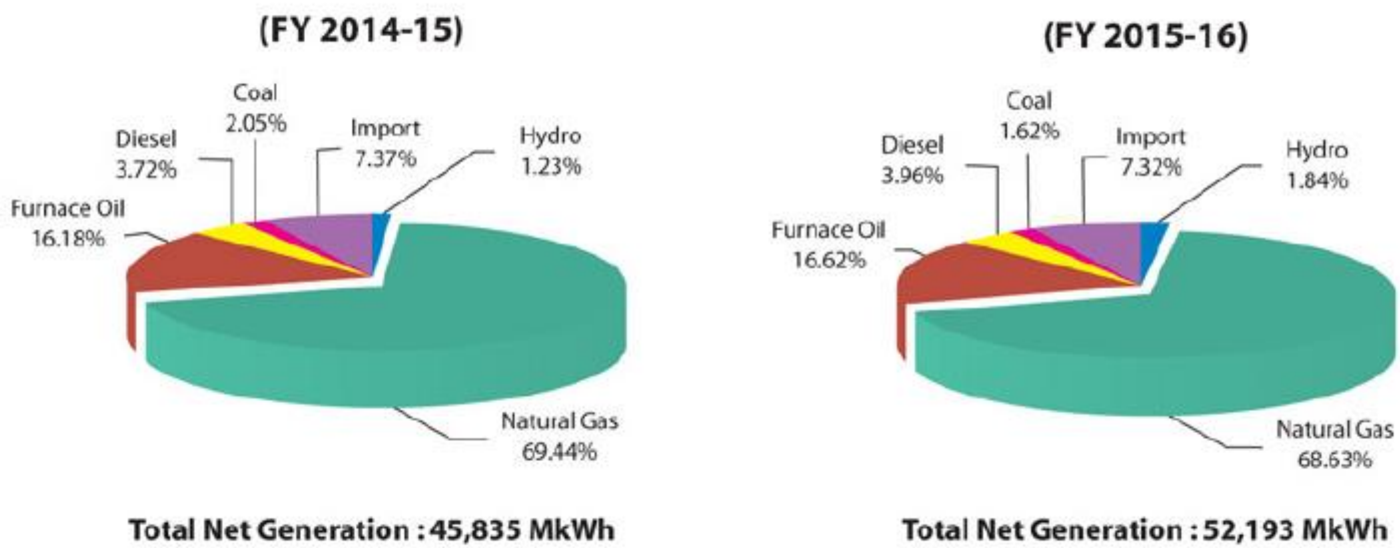
ECONOMIC ANALYSIS

8.1 Background

The energy sector is an important one for all the various countries of the world, and especially, the countries that are developing from an economic point of view. A main issue regarding the energy supply and demand in Bangladesh is that, whereas the energy demand is expected to continue increasing rapidly, domestic production of natural gas that accounts for more than half of the country's energy demand is coming to saturation (as per Survey on Power System Master Plant 2016 by JICA) .

Following figure shows the yearly comparison of net electricity generation in the Bangladesh by fuel type:

Figure 46: *Comparison of net electricity generation in the Bangladesh by fuel type*



Source: *BPDB annual report 2015-2016*

Both above figure of electricity generation and primary energy scenario from Survey on Power System Master Plant 2016 by JICA report of Bangladesh indicates that, in Bangladesh domestic production of petroleum is far less than that of natural gas, and the country's demand mostly depends on imports. The consumption of petroleum for power generation has been increasing rapidly since

2011, but that the amount of domestic production has not increased during that period, which implies that the dependence of power generation on imported petroleum has been progressed.

Based on above analysis and primary energy supply scenario of Bangladesh for future, HFO & Diesel seems gap filling fuel for power generation in Bangladesh. For this economic analysis in this FSR we have considered HFO & Diesel as baseline fuel.

Considering challenges of primary fuel, more emphasis has been given in power generation through renewable energy. This would especially meet the demand in areas where grid supply is not possible. The establishment of Sustainable and Renewable Energy Development Authority (SREDA) is aimed to provide dedicated institutional support to promote renewable energy. The two main areas of renewable energy are solar and wind power.

Bangladesh has enormous potential for wind energy, mainly in the coastal areas, hoarse and offshore islands. Government has a plan to generate electricity from wind power under public and private initiatives.

Government of Bangladesh (GOB) has taken a systematic approach towards renewable energy development. The initiative includes development of relevant policy and institutional development. As per the National Renewable Energy Policy 2008, the plan is to add generation capacity of 2,000 MW by 2020 from renewable sources. In addition, the Ministry of Power, Energy and Mineral Resources has announced in 2013 to develop 500 MW of installed generation capacity from solar energy through Asia Solar Energy Initiative (ASEI).

Bangladesh has received concessional climate financing from the Scaling-up Renewable Energy Program in Low Income Countries (SREP) of the Climate Investment Funds (CIFs) for implementing the SREP Investment Plan for Bangladesh that was prepared by GOB and endorsed by the SREP Sub-Committee. The Investment Plan includes i) grid-connected renewable energy and ii) off-grid solar PV mini-grids and irrigations. Under the grid-connected renewable energy project supported by the World Bank, Bangladesh plans to use concessional resources from SREP to leverage financing for the development of 170 MW of utility-scale solar PV and 32MW of grid-connected rooftop solar PV. SREP support would help catalyze private investment in a first round of ground- and roof-mounted solar PV plants, and show the potential for deploying solar PV on a commercial basis.

In the course of promoting renewable energy development program, the Electricity Generation Company of Bangladesh Limited (EGCBL) has identified a potential grid-connected renewable energy project.

This project is a part of renewable energy development plan of GOB.

Economic Analysis considers the project associated externalities and benefits, as explained in following sections with results.

8.2 Externalities

Externalities are impacts from the electricity generation activity, e.g. lung diseases from air pollution, which have no financial bearings on the owner of the power plant, but which result in economic costs or benefits to society.

The World Bank's Handbook on Economic Analysis defines externalities as "The difference between the benefits (costs) that accrue to society and the benefits (costs) that accrue to the project entity."

In other words, externalities can be:

- Local – such as the health damage cost incurred from NOx, SO2 and particulate matter e.g. thermal power plants.
- Regional – such as the impact of a hydro project on fisheries many miles downstream and perhaps even in a different country.
- Global – such as the damage cost from thermal power generation whose impacts are felt by the entire world e.g. global warming due to GHG emissions.

The difficulty is to quantify the costs and benefits in terms of money, so that the externalities can be included in socio-economic evaluations. Then the political issue is whether and how to introduce corrective measures to include (internalise) the externalities in energy prices at the least cost for society in order to create a level playing field for all technologies.

There are five different externalities:

1. Climate change; greenhouse gasses, in particular CO2 and CH4.
2. Other pollution: Air emissions (SOx, NOx, particles, and radioactive emissions) and nuclear accidents.
3. Grid integration; primarily extra costs to electrical infrastructure, power balancing costs and reduced capacity value for wind turbines and additional reserve capacity for nuclear power plants.
4. Security of fuel supply; substitution of fuel imports with indigenous resources.
5. Local benefits; primarily employment.

8.3 Project Benefit

Different kinds of power sector investment project have different kinds of benefits, some of which may be difficult to quantify. Below are main benefits and issues of Grid connected renewable energy:

- Avoided cost of grid connected thermal generation
- In addition to the main benefit of avoided thermal generation, various additional benefits are proposed for such projects, such as Energy Security and macroeconomic benefits.

This renewable energy project will fuel economic growth, create new employment opportunities, enhance human welfare, and contribute to a climate safe future.

The macroeconomic impacts of renewable energy deployment presented in this FSR were obtained based on a macro-econometric analysis, using the 3E benefits (Economy, Environment & Energy Security).

8.4 Economic Analysis

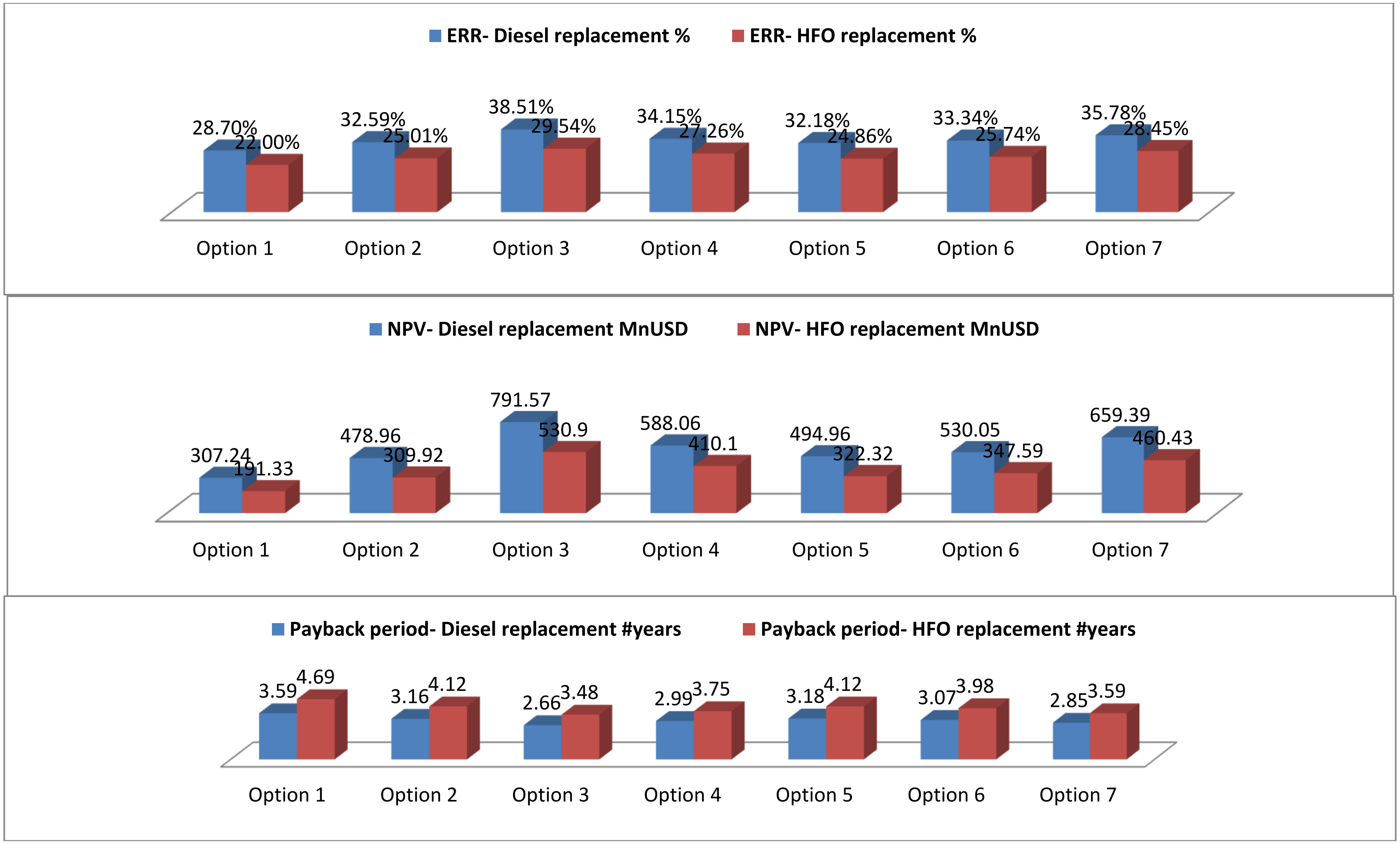
Considering externalities and benefits economic analysis has been done, following tables and figures show the economic analysis result of this project:

Table 51: *Economic analysis result of the project Options - 1 to 7*

Parameter	Unit	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
ERR- Diesel replacement	%	28.70%	32.59%	38.51%	34.15%	32.18%	33.34%	35.78%
NPV- Diesel replacement	MnUSD	307.24	478.96	791.57	588.06	494.96	530.05	659.39
Payback period- Diesel replacement	#years	3.59	3.16	2.66	2.99	3.18	3.07	2.85
ERR- HFO replacement	%	22.00%	25.01%	29.54%	27.26%	24.86%	25.74%	28.45%
NPV- HFO replacement	MnUSD	191.33	309.92	530.90	410.10	322.32	347.59	460.43
Payback period- HFO replacement	#years	4.69	4.12	3.48	3.75	4.12	3.98	3.59

Source: *WFMS Analysis*

Figure 47: *Project Options' Economic Analysis Comparison*



Source: *WFMS Analysis*

As can be seen from the above table and figure that, among proposed seven Options, Option 3 seems more economically viable compare to other options, but as per the requirement of the country, site and client to cater livelihood along with this project, Option 7 (recommended option) seems suitable among all.

Hence from this feasibility study we have recommended Option 7 as more suitable to the site. However decision is open with the client to choose any Option as per their further requirements.

Table 52: *Economic analysis (3E evaluation) result of the recommended Option 7*

Economic Analysis (3E evaluation) of the recommended final option					
3E	**Parameter**	**Unit**	**Diesel Replacement**	**HFO Replacement**	**Remark**
Economic	ERR	%	36%	28%	
	NPV	m USD	659.39	460.43	
	Payback period	Years	2.85	3.59	
	SC-CO2	m USD	88.20	100.73	This assumes social carbon value of avoided CO2 emissions as per USEPA, considered for entire project life @ 14 USD/tCO2, 5% average, 2020-2030.
Environment	GHG emissions avoidance	ktCO2e	6299.74	7194.87	Carbon emission savings over the life of the project
Energy Security	Avoided fossil fuel cost	m USD	2574.50	1915.35	Savings from fuel reduction will further cut import costs of these items.
Social	Social benefits in terms of incomes, health, education, employment and general human well-being from power, connectivity and such additional support infrastructure for the project				Many other indirect social benefits may result from this project. A separate detailed study may be done for exact estimation of the same.

Note: *Taken assumptions for this analysis is given in the excel sheet, that will be shared separately as Financial Model.*

Following tables show the job creation scenario of different technology projects:

Research conducted by EPRI (Electrical Power Research Institute, California), has assessed the direct employment of various RE technologies per MW of RE capacity:

		Wind	Geothermal	Solar PV	Biomass
Construction	job-years	2.57	4.00	7.14	3.71
O&M	jobs	0.29	1.67	0.12	2.28

Assuming technical lifetimes of 20 years for wind and biomass and 30 for photovoltaics and geothermal, the number of job years created for each technology is calculated in the table below:

Job creation (job-years)	Wind	Geothermal	Solar PV	Biomass
Construction	2.57	4.00	7.14	3.71
O & M	5.8	50.1	3.6	45.6
Total	**8.37**	**54.1**	**10.74**	**49.31**

8.5 Conclusion

Above Economic analysis shows that, among proposed seven Options, Option 3 seems more economically viable compare to other options, but as per the requirement of the country, site and client to cater livelihood along with this project, Option 7 (recommended option) seems suitable among all.

Hence in this FSR we have considered Option 7 more suitable to the site. However decision is open with the client to choose any Option as per their further requirements.

This economic analysis shows that, the project is having 3E benefit for the country at macro level, which this project can achieve through different means like GHG emissions avoidance, SC-CO2, social benefits, energy security, health benefit and job creation etc.

This project is supporting following SDGs (Sustainable Development Goals):

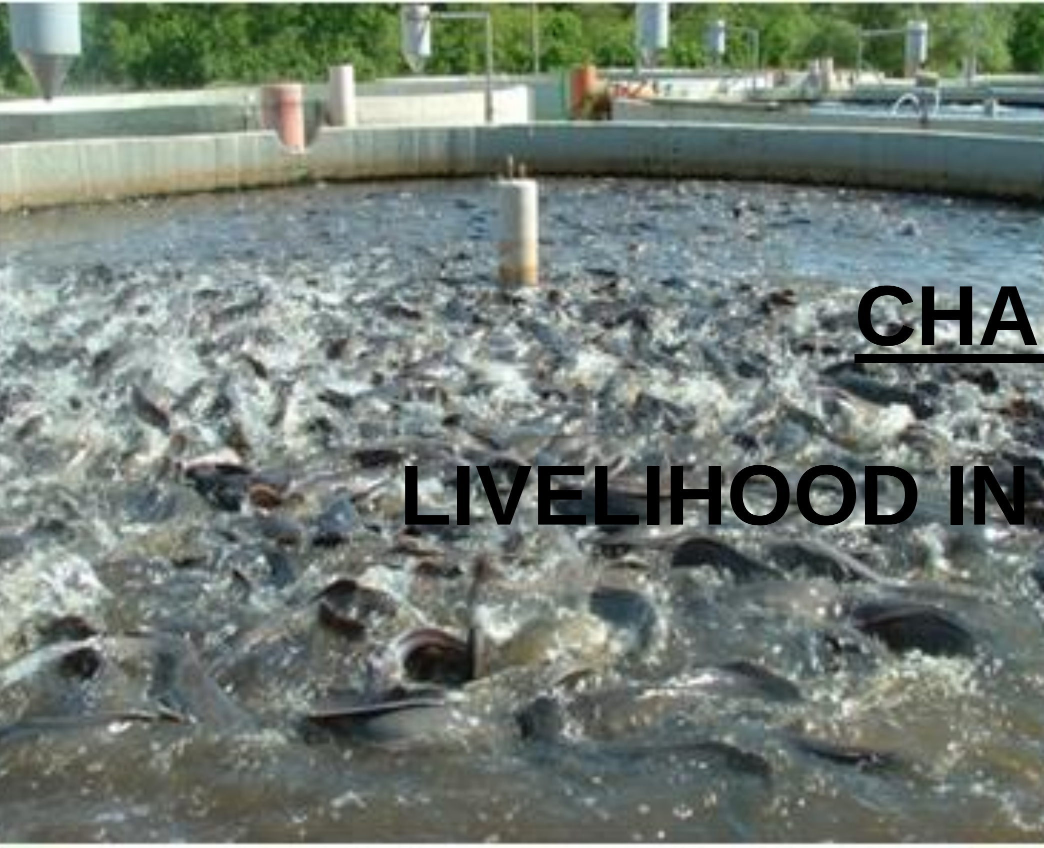
IV. Goal 7 “Clean energy for everyone”: Secure access to affordable, reliable, sustainable and modern energy for everyone.
V. Goal 9 “Industrial and technological innovation and social infrastructure”: By developing robust infrastructure, promote inclusive and sustainable industrialization and also expand technological innovation.
VI. Goal 13 “Urgent handling of climate change”: Take urgent countermeasures for climate change and its impact.

Hence such projects should be encouraged to be developed as a pilot for others.

Note: *There is further need of detailed study of externalities and benefits of this project.*

CHAPTER – 9

LIVELIHOOD IN THE PROJECT SITE



Bangladesh is having land scarcity and higher population density per square KM, therefore, to utilize the available land in most optimum way to fulfil country's needs and generation of more livelihood options for the citizens is the major consideration for the GoB.

This project site is also considering the sustainable development – environment benefit through renewable energy, economic benefit through additional power generation and social benefit through livelihood generation.

Considering all aspects of sustainability, the option 7 seems best fit to fulfil these criteria. Based on this consideration the final selected option to go ahead with is Option 7 - 200 MWac (272 MWdc) Solar PV along with utilization of remaining land for livelihood purpose e.g. fisheries.

Besides the electricity production of from the RE plant, the possibility of an additional land utilisation has been analysed for the following usage scenarios.

a. Fishery
b. Cattle breeding
c. Farming

a. Fishery

Fish farming might be an option as the demand of land compared to other options is relatively low. For risk mitigation separated areas are required. A possible location of the ponds could be within the wind farm.

The usage scenario of fish farms around the WTGs area seems reasonable as the land is having existing water body in his area and the south side of the site would be water immersed throughout the year (as told by the client).

Other option is fish farming beneath the solar PV modules (with consideration of technical aspects and safety).

The possible fish farming analysis has been done in direct consultation with the Fishery Experts from the Department of Fishery of Bangladesh and other recognised International fishery expert in Bangladesh (visited Bangladesh exclusively for this consultation from 23rd July to 27th July 2017).

As per consultation and discussion, the fish farming can be done at the proposed project site in two ways:

1.) Separately defined a fish farming area in the proposed project site along with RE power project i.e. Option 4 & Option 7 (recommended option).

2.) Fish farming beneath the solar PV modules (with some considerations) i.e. Option 5 & Option 6.

As per consultation with fishery experts in the Bangladesh followings are the inputs for the fishery at the proposed project site (irrespective to layout of proposed project activity):

1.) Brackish water fish species can be farmed at the site like Telapia.
2.) Semi Intensive fish farming culture gives 4-5 MT/acres/year production with less cost of farming culture development e.g. BDT 80 / kg for OPEX and BDT 15 / kg for CAPEX.
3.) Intensive culture gives 40 MT/acres/year but with large amount of development investments.
4.) For suggested semi intensive fish farming culture following pond system is required:
    a. 50 decimal (1 decimal equals to 40 m^2) Egg pond of 1 m depth.
    b. 50-100 decimal Fingerlings pond of 1 – 1.5 m depth).
    c. 200-250 decimal Market size maturing pond of 1.5 – 2.5 m depth.
5.) 5-6 feet vertical clearance (from pond water level) and 5-7 m horizontal distance is required for daily fishery activity/management.
6.) Semi Intensive culture fishery requires 6-8 hours of sunlight per day and does not require aeration for aqua life, however during cloudy days aeration may be required and it can be done through manual pedalling.
7.) During rainy season the brackish water specie can survive with rainy water mixing.
8.) For daily fish feeding can be done through country boat and bucket.
9.) Under water tray can be used for regular fish feeding (1-2 times in a day).
10.) A special harvesting net can be designed for this case of fishery beneath the solar PV modules.
11.) Whole sale price of fish product in the Bangladesh is around BDT 140 per kg.
12.) 10-17 kg/capita/year fish consumption is in Bangladesh.

Following image shows the example for an elevated PV plant concept for a fish farm underneath a 200MW PV plant covering an area of 300 hectares in Zhejiang, China.

***Figure 48:** Eelevated PV plant concept for a fish farm underneath a 200MW PV in Zhejiang, China*

***Source:** www.pv-magazine.com*

b. Cattle breeding

In general, the land would be suitable for cattle grazing. This scenario however, would require sufficient fencing around the PV plant to protect the PV plant equipment. Allowing cattle grazing within the area of the PV plant is not reasonable in light of life risk, possible damage of equipment and restrictions to component warranties.

c. Farming

There are mainly two seasonal types of crops growing in this area, which is paddy during early monsoon (34 kg paddy / decimal) and lentil at dry season (15 kg lentil / decimal).

Here in project area those species of plants can be planted which can grow in brackish water, following are benefits of planting those species:

1.) These plant species can improve the water quality via phyto-remediation process
2.) Aesthetic purpose
3.) Livelihood
4.) Aqua life

In order to improve the usability of the land for farming activities the application of an elevated structure might be an option. The idea of an elevated structure is to reduce the obstacles that limit the activities of farming to a minimum. Disadvantages of this option are:

There are some research projects working on the optimization of using the same land for the two purposes of growing crops and generating electricity. The challenge is to design and built the mounting structure to secure adequate sunlight for crops and enough space for agricultural machinery to be able to move around and sufficient concentration of PV for an economic operation of the PV plant as shown in the Figure below.

Source: *http://www.agrophotovoltaik.de/english/research-site/*

Disadvantages of this option are:

- Additional costs for construction
    - for the mounting structure (pile length and static requirements)
    - module mounting and assembling of the mounting structure
    - electrical installation: cable laying and mounting of combiner boxes

  - platforms for or protection of inverter/transformer stations
- Additional costs for O&M
  - module cleaning and inspection
  - measurements
  - inspection of mounting structure and re-torquing
  - Maintenance issue during flooding.
- No utility-scale applications so far
- Safety (life risk) is an issue, when people are allowed in solar area.
- Security (theft damage) is a serious concern.

Conclusion

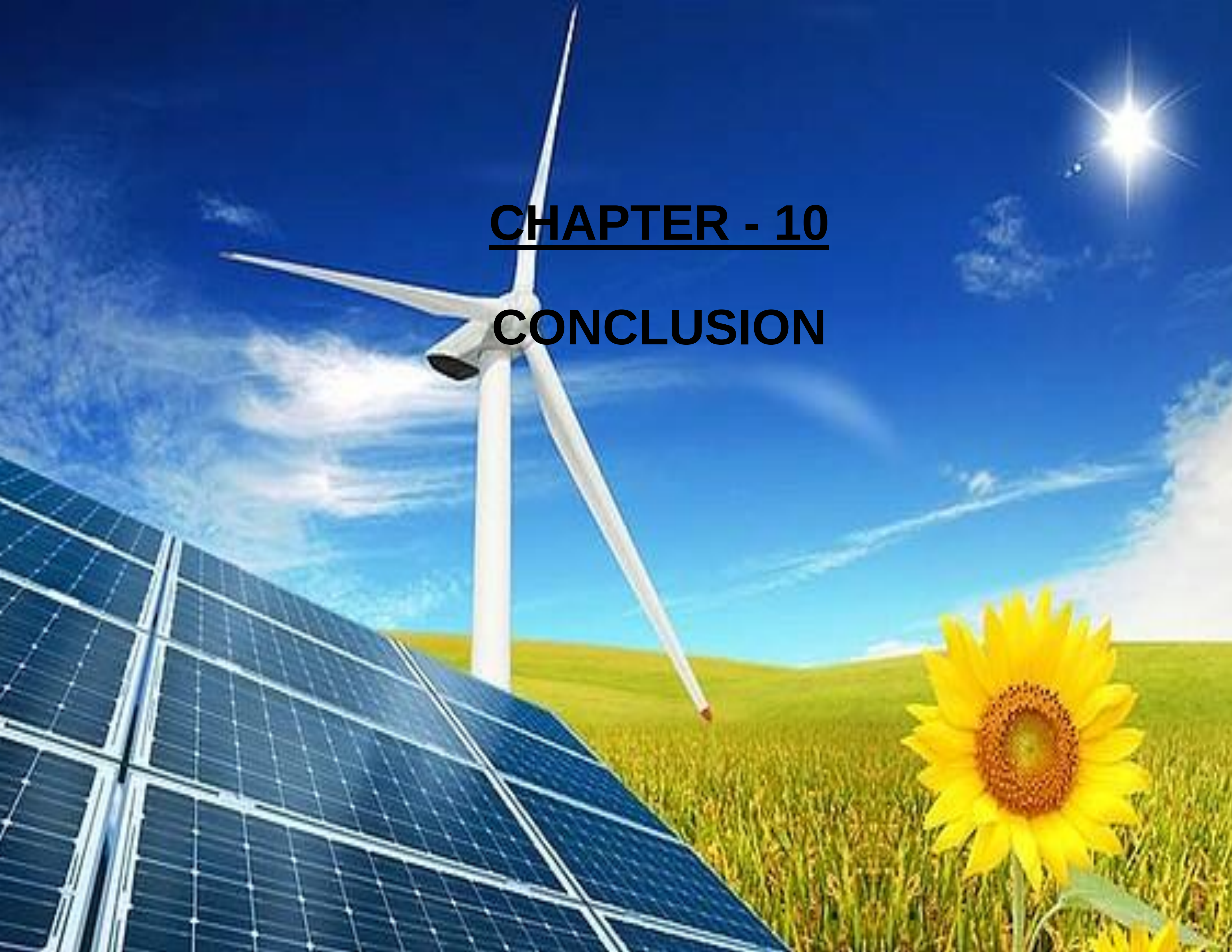
Presently the proposed project land is not having any livelihood activities ongoing like agriculture, fishery and/or any other land use. The land is less fertile and saline in nature due to presence near coast of Sea. Proposed livelihood activities analysis shows that agriculture farming and cattle breeding do not seem suitable to the site conditions and proposed project activity, but, fishery (brackish water species) activity can be done at the site. Intensive fish culture on open land is a better option compare to Semi-intensive fish culture beneath the panels (as explained in the Capacity Mix Chapter with rationale.

Hence intensive Fishery can be done in a separately defined area in the proposed project site along with only solar PV power project. Option 7 (recommended option) suffices this purpose. The Option 7 considers a separated area for additional land utilisation option (intensive fishery) with small/large pond culture). The recommended scenario allows up to use 25% of the site for separate livelihood option within a clearly defined and safe area (refer Option 7 layout for further understanding in Capacity Mix Chapter).

From the north and west side of the project site some small fishery ponds and agriculture activity is happening but they are away from the site and not dependent on the site in any way. However the detailed ESIA study needs to be conducted for this project during implementation stage by the accredited third party, hence that study will cover the impacts of this project on nearby communities and their livelihood and vice versa case.

CHAPTER - 10

CONCLUSION



1. Recommended final option is "200 MWac solar PV with Intensive Fishery on balance land without any wind power project".
2. The project shall be developed in two phases
   a. Phase -1 (50 MWac)- by EGCB,
   b. Phase-2 (150 MWac)- PPP Mode. Fishery to be separately set up under PPP mode
3. Power Evacuation: Mirsarai 230 kV GSS of PGCB Or BEZA substation of PGCB (under construction) can be an option for power evacuation for this RE project.
4. Transportation & Site Approach: Strengthening of existing road with 4.5 m width of 7.5 KM length (connecting the site to National Highway) as per Bangladesh road category type-7 is recommended for the project.
5. Natural Stream Management: Two natural streams are passing from the site. We have proposed to restore both the natural streams with its natural course along with both side embankment.
6. The LCOE is estimated for Option 7 (recommended option) is 10.04 USD cents / kWhr. This is cheaper compare to power from diesel and HFO generators, is 25.80 to 38.40 Tk/kWh is average unit cost of electricity generation by HSD and 14.15 to 19.30 Tk/kWh by HFO (BPDB, annual report 2015-2016).
7. Financial and Economic analysis shows that, among proposed seven Options, Option 3 seems more economically viable compare to other options, but as per GOB's requirements and sustainable use of land to cater livelihood along with this project, Option 7 (recommended option) seems suitable among all. Hence in this FSR we have considered Option 7 more suitable to the site. However decision is open with the client to choose any Option as per further requirements.
8. Following table shows the results of Option 7 at the proposed site (P75):

Parameter	**Unit**	**Option 7 (solar PV with fishery and no wind)**
		Solar PV
Technology		Solar PV: Fixed-tilt solar PV system based on central inverter and polycrystalline module technology. Wind:

		Gamesa G114 2.0MW Model
Capacity	MWdc	272
	MWac	200
	Total MWac	200
Net Energy Yield	GWhr/yr	392.70
Total Area	Ha	269.13
CAPEX	m USD	237.00
OPEX	m USD	3.42
LCOE	USD cents / kWh	10.04

9. To avoid flooding hazard, combination of Dike and elevated structure will be used.
10. The recommended option 7 project activity would reduce the GHG emissions around **6299738 tCO2e** by replacing Diesel **Or 7194872 tCO2e** by replacing HFO in its project life i.e. 25 years, which would occur in business-as-usual case.
11. There is further need of detailed hydrology/natural disaster impacts/climate change impacts study before the vendor engineering e.g. study through existing 2-dimensional flood model for the project area with recent satellite imageries/ topography to refine and improve the forecast of disaster risk on the site beyond the 50 years. It will include risks, mitigation measures, the proposed embankment and other drainage facilities (pumps, drainage network, regulators, retention ponds, drainage canals) and restoration of natural streams.
12. For detailed financial and economic assessment please refer Appendix P.

CHAPTER - 11

ASSUMPTIONS OF THE STUDY

Assumptions for the Feasibility Study

1. Solar PV assessment has been carried out using solar GIS data provided by World Bank. No further refinement is expected in this regard.

2. 10-min interval wind data from 120 m met-mast is not available for the project area, therefore all wind related calculations have been carried out considering Modern-Era Retrospective analysis for Research and Application (MERRA) data which is widely used internationally and has lower uncertainty. Flow modeling has been carried out using boundary layer theory, a methodology proprietary to WFMS. This methodology has been validated using actual mast observation across South Asia and South East Asia. The decision to be taken will need further confirmation by installing a measurement mast and measuring wind speeds for at least two full wind seasons. Regen is doing the on region wind measurement study but the study will be completed by 2018, hence the wind project should be developed in next year once the actual regional wind data is available.

3. Based on discussions and suggestion from PGCB, Mirsarai 230 kV GSS of PGCB Or BEZA substation of PGCB (under construction) can be an option for power evacuation for this RE project. For this feasibility assessment study we have considered Mirsarai 230 kV GSS, however further power evacuation option and arrangement depend on the detailed grid connectivity and stability study of PGCB and client's decision.

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court to
on, a matter
—SYN.
ref.er.ence
referred; esp.,
person, committee,
connection; regard

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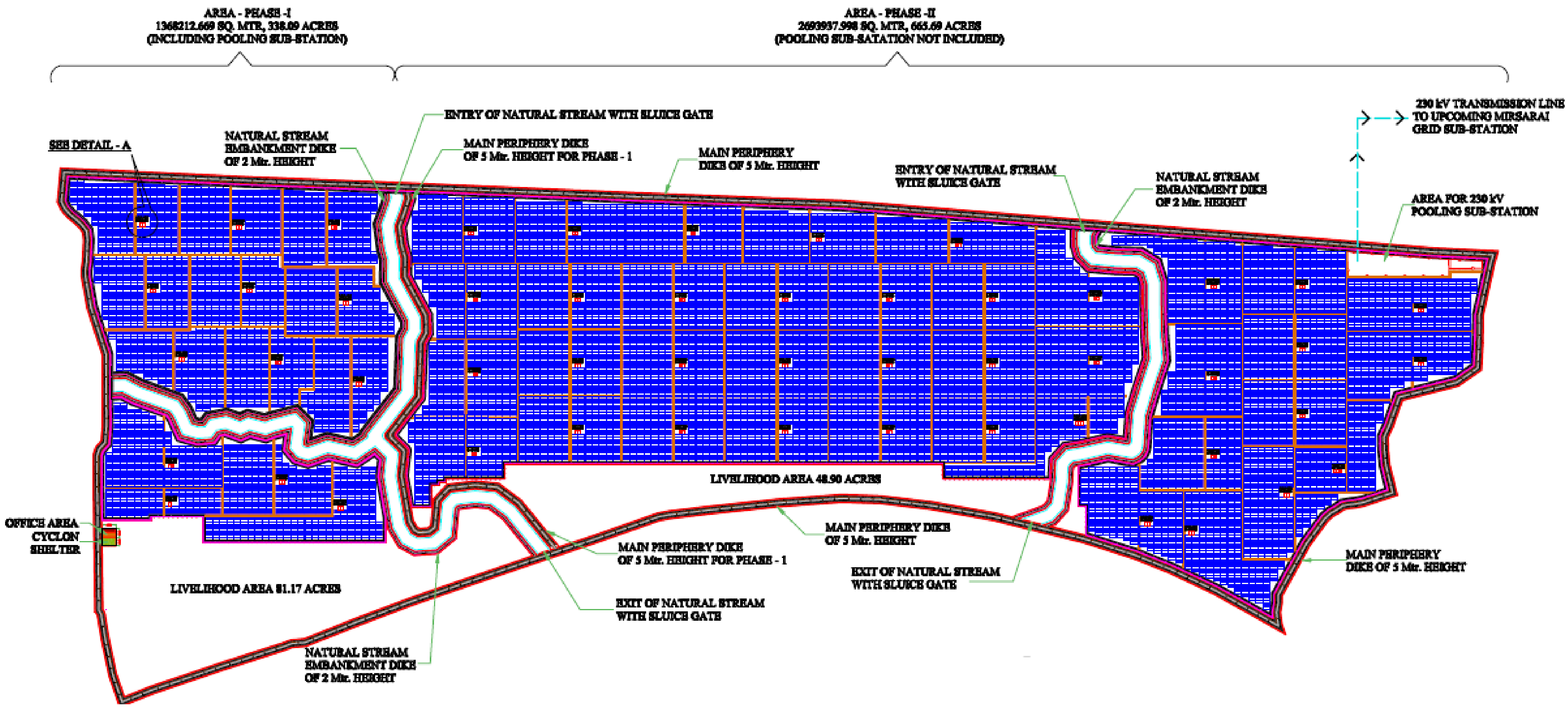
APPENDIX


44.03
46.83
35.95
31.41
28.43
27.91
28.02
22.82
2M
1M
48
46
44
42
32
30
28
26
24
22
$ (Weekly) 0.0186
(20) 0.0222
0.0350
0.0325
0.0300
0.0275
0.0250
0.0225

Appendix A: Conceptual design of 200 MWac Solar PV with livelihood



Appendix B: Energy yield – solar PV simulation

PVSYST V6.67	Sunaura Technologies Pvt. Ltd (India)	13/12/17	Page 1/6
	Unitech Business Zone, Golf Course Ext Rd, South City II, Sector 50, Gurugram		

Grid-Connected System: Simulation parameters

Project :	**Bangladesh Project - Option 7 Project**				
Geographical Site	**Sonagazi Upazila, Bangladesh**			Country	**Bangladesh**
Situation		Latitude	22.88° N	Longitude	91.39° E
Time defined as		Legal Time	Time zone UT+6	Altitude	11 m
		Albedo	0.20		
Meteo data:	**Sonagazi Upazila, Bangladesh**		Meteonorm 7.1 (1981-2010), Sat=100% - Synthetic		

Simulation variant : **PVsyst Simulation for 200 MW PV Power Plant at Bangladesh**

Simulation date 13/12/17 13h35

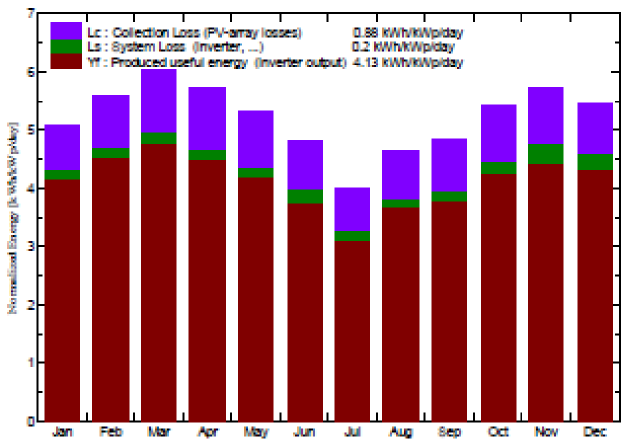
Simulation parameters					
Collector Plane Orientation		Tilt	15°	Azimuth	0°
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon		Free Horizon			
Near Shadings		No Shadings			
PV Array Characteristics					
PV module	Si-poly	Model	**CS6X - 315P MIX**		
Original PVsyst database		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	20 modules	In parallel	43175 strings
Total number of PV modules		Nb. modules	863500	Unit Nom. Power	315 Wp
Array global power		Nominal (STC)	**272003 kWp**	At operating cond.	244143 kWp (50°C)
Array operating characteristics (50°C)		U mpp	654 V	I mpp	373159 A
Total area		Module area	**1656908 m²**	Cell area	1513266 m²
Inverter		Model	**Sunny Central 1000CP XT**		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	596-900 V	Unit Nom. Power	1000 kWac
				Max. power (=>25°C)	1100 kWac
Inverter pack		Nb. of inverters	200 units	Total Power	200000 kWac
PV Array loss factors					
Array Soiling Losses				Loss Fraction	3.0 %
Thermal Loss factor		Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss		Global array res.	0.029 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation				Loss Fraction	2.0 %
Module Quality Loss				Loss Fraction	0.0 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Strings Mismatch loss				Loss Fraction	0.20 %

Incidence effect (IAM): User defined IAM profile

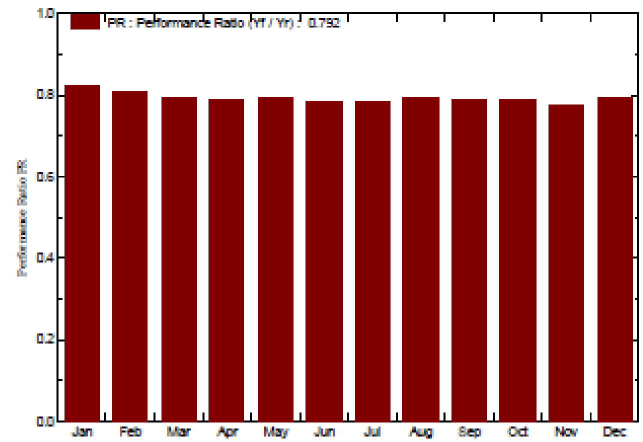
10°	20°	30°	40°	50°	60°	70°	80°	90°
0.998	0.998	0.995	0.992	0.986	0.970	0.917	0.763	0.000

System loss factors				
AC wire loss inverter to transfo	Inverter voltage	405 Vac tri		
	Wires: 3x30000.0 mm²	15 m	Loss Fraction	1.5 % at STC
External transformer	Iron loss (24H connexion)	800852 W	Loss Fraction	0.3 % at STC
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	0.0 % at STC
Unavailability of the system	3.7 days, 5 periods		Time fraction	1.0 %

Normalized productions (per installed kWp): Nominal power 272003 kWp



Performance Ratio PR

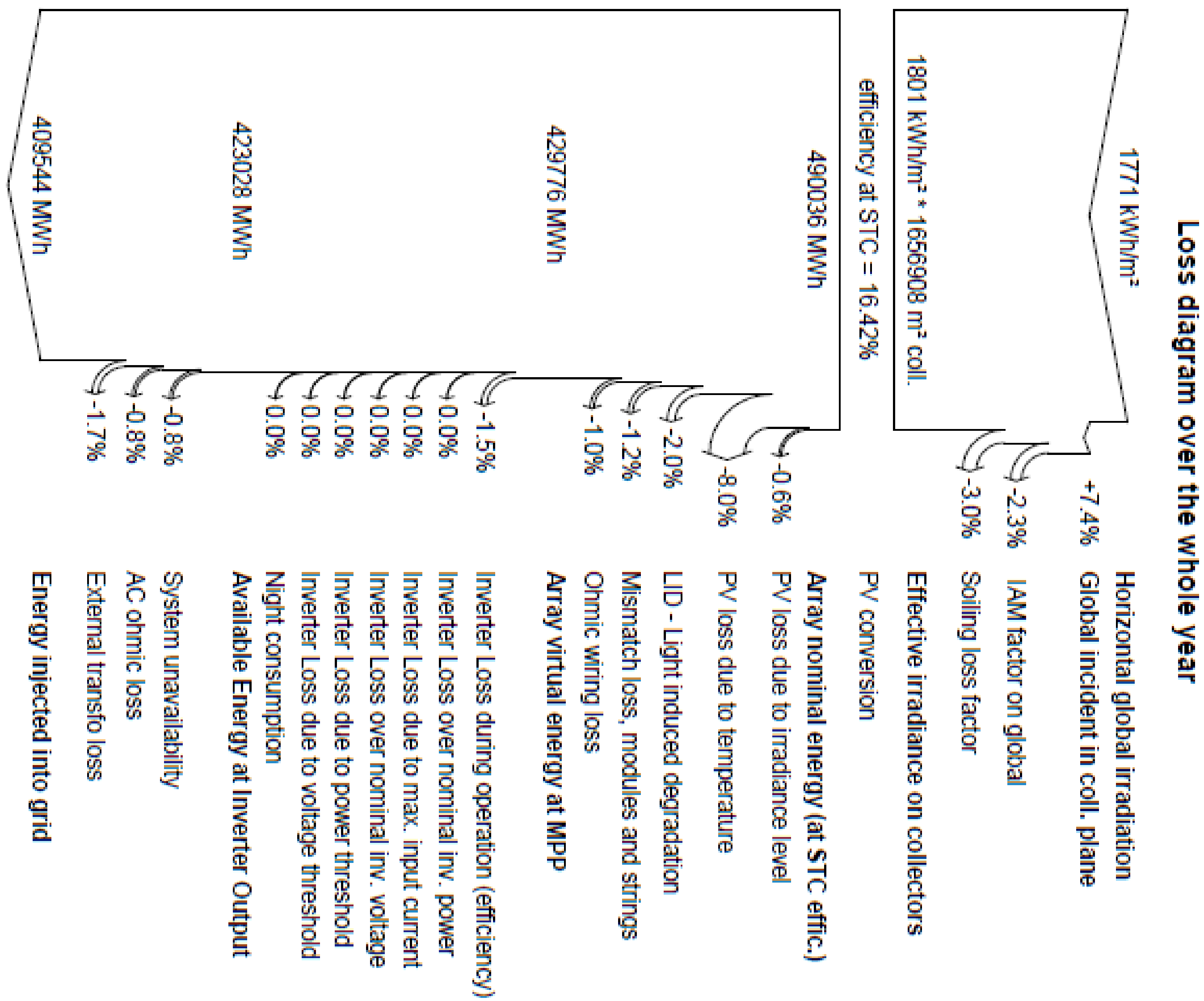


PVsyst Simulation for 200 MW PV Power Plant at Bangladesh

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	130.5	49.48	20.21	157.6	149.6	36604	35159	0.820
February	137.6	55.69	22.90	156.8	149.0	35829	34435	0.807
March	173.7	71.24	26.21	186.7	177.3	41831	40228	0.792
April	168.8	87.18	28.01	171.1	161.9	38227	36772	0.790
May	169.5	99.51	28.78	164.9	155.8	36908	35488	0.791
June	150.5	96.10	28.01	144.5	136.2	32598	30800	0.784
July	128.3	77.77	28.10	123.4	116.4	27686	26261	0.782
August	144.8	91.84	28.26	143.3	135.2	32279	30972	0.795
September	139.7	69.32	27.85	144.7	136.9	32310	30981	0.787
October	151.0	62.01	27.78	167.9	159.3	37582	35932	0.787
November	142.2	43.10	24.78	171.5	163.1	38953	36076	0.774
December	134.2	37.14	21.83	168.7	160.3	38885	36440	0.794
Year	1770.8	840.38	26.07	1901.2	1800.9	429693	409544	0.792

Legends:			
GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid


Loss diagram over the whole year
1771 kWh/m²
Horizontal global irradiation
+7.4%
Global incident in coll. plane
-2.3%
IAM factor on global
-3.0%
Soiling loss factor
1801 kWh/m² * 1656908 m² coll.
Effective irradiance on collectors
efficiency at STC = 16.42%
PV conversion
490036 MWh
Array nominal energy (at STC effic.)
-0.6%
PV loss due to irradiance level
-8.0%
PV loss due to temperature
-2.0%
LID - Light induced degradation
-1.2%
Mismatch loss, modules and strings
-1.0%
Ohmic wiring loss
429776 MWh
Array virtual energy at MPP
-1.5%
Inverter Loss during operation (efficiency)
0.0%
Inverter Loss over nominal inv. power
0.0%
Inverter Loss due to max. input current
0.0%
Inverter Loss over nominal inv. voltage
0.0%
Inverter Loss due to power threshold
0.0%
Inverter Loss due to voltage threshold
0.0%
Night consumption
423028 MWh
Available Energy at Inverter Output
-0.8%
System unavailability
-0.8%
AC ohmic loss
-1.7%
External transfo loss
409544 MWh
Energy injected into grid

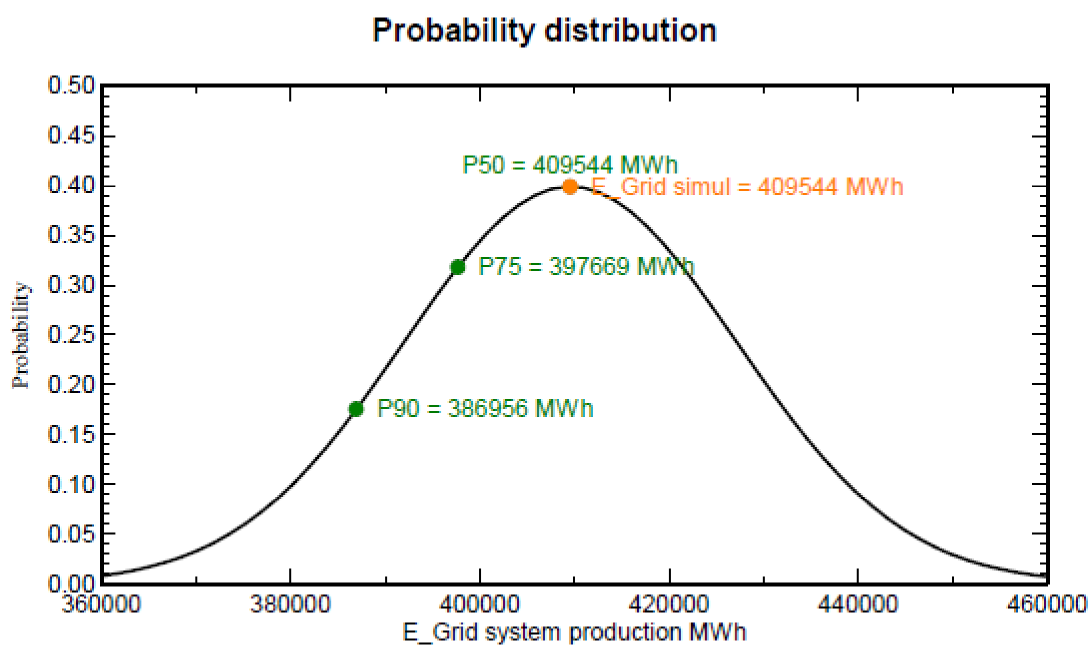
The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

Meteo data source		Meteonorm 7.1 (1981-2010), Sat=100%
Meteo data	Kind	TMY, multi-year
Specified Deviation	Climate change	0.0 %
Year-to-year variability	Variance	3.5 %

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	2.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	4.3 %	(quadratic sum)

Annual production probability	**Variability**	**17615 MWh**
	P50	**409544 MWh**
	P90	**386956 MWh**
	P75	**397669 MWh**



Appendix D: Risk assessment and comprehensive risk matrix and recommended mitigating measures - as applicable

Category of Risk	Risk manifestation event	Allocated to Party	Mitigation
Climate change/Natural Disaster Risk	Tidal Inundation	Project Developer	The major adaptation measure against flooding in the coastal region of Bangladesh is the construction of earthen dike along the rivers as well as parallel to coastline. The dikes are designed primarily to prevent flooding during high astronomical tides and are found useful during cyclone-generated storm surge too.
	Tropical Cyclones and Storm Surges	Project Developer and Sponsor/Forest Department (Gov. of Bangladesh)	Increasing Dike Height: Dikes obstruct the penetration of surge wave to the land and even if the surge overtops them, the wave energy reduces to a considerable extent. The Project Specific Proposed Dike height has been defined after analysis and assessment of last 50 years historical meteorological stations' data and forecasted for 25 years and regression analysis has been done to arrive at the suitable Dike height. The Coastal Afforestation: In the recent years, plantations in the coastal area as well as along the Dikes are being extensively conducted to enhance flood mitigation measures in the coastal zone by the Forest Department in Bangladesh. This Project will also have the Afforestation along the Dike.
	Coastal Morphological Dynamics (Erosion)	Sponsor/Forest Department (Gov. of Bangladesh)	Mangrove Greenbelt: The Government of Bangladesh is now executing the Green Belt Project in the coastal areas. This is a participatory reforestation program aimed at reduction of natural disasters as well coastal erosion. Afforestation is environment friendly and it helps to stabilize the land and also raise the ground level that will reduce inundation depth. The primary objective of developing mangrove plantations would be to mitigate disastrous effects of cyclones, storm surges and erosion. Several projects with forest management components have been implemented or are currently being implemented in the coastal zone by GoB. Project can leverage those ongoing activities of the GoB for this Mangrove greenbelt development. The Project can have *Sonneratia apetala, Avicenna*

			officinalis, Excoecaria agallocha, Bruguiera gymnorhiza and Nypa fruticans tree species to be planted (as per Bangladesh Coastal Mangrove Greenbelt/afforestation study and project (Serajuddoula et al. 1995).
	Seismic	Project Developer	The project and its associated infrastructure will be designed and developed considering the applicable zone wise seismic risk and impact.
	Tsunami	Project Developer and Sponsor	Tsunami preparedness — linking to the cyclone preparedness programme: Disaster preparedness, among other activities, includes construction of cyclone shelters and effective warning mechanisms for remote local coastal communities. Most of the cyclone shelters are used as schools during normal periods of the year. Since the project site will be having people living at the site for operation and Maintenance, therefore there is need of development of cyclone shelters and effective warning mechanisms.
Construction risk	Cost overrun	Project Developer	Fixed price, turn-key contract, experienced contractor
	Time overrun	Project Developer	Fixed completion (Date certain) in EPC contract
	Failure to satisfy specified performance	Project Developer	Performance guarantees in TKCC (penalty applicable)
	Delay in connection to grid	Project Developer	To be taken care of in the Power Purchase Agreement (PPA)
	Approvals, permits and Clearances	Project Developer & Governmental Authorities	All the requisite approvals, permits and clearances for the project (Statutory and Non-Statutory) should be obtained by the Project Developer by the appropriate regulating Governmental Authorities. The Governmental Authorities (subject to approval requirements and Project Developer's capacity to provide same, as per contractual stipulations) shall assure issuance. Obtaining all approvals, permits and clearances are a prerequisite for financial closure.
	Completion	Project Developer	Liquidated damages for delay in task/project completion on account of default of the EPC contractor has to be provided in the EPC contract for each component of project procurement.
Technolo	Relatively new	Sponsor	Full recourse to sponsors until completion

gical/Functional risk	technology		
Operational & Management risk	Disruption in production, mal-performance	Operator	O&M contract with incentives and penalties; Operator = Sponsor, incentivized by dividend shortfalls or over-performance
	higher cost than scheduled for instance, migrating sand dunes or higher cost for cleaning	Operator, Sponsors	contingent equity (guarantees) to come up for curing measures (e.g. sand dune walls)
Market risk	Lower sales volume	Power off-taker	Long-term PPA with defined purchase volume OR merchant plant risk, in which case higher equity in project as buffer to banks
	Lower prices	Power off-taker	Long-term PPA with defined prices or merchant plant risk, in which case higher equity percentage as buffer to Lenders
Energy Yield Risk and Solar Resource risk	Less solar irradiation than predicted	Sponsors	Contingent equity injections from Sponsors, that could be used e.g. to enlarge solar field
Financial risk	FX risk	Sponsors/ Lenders	Hedging, local currency funding in debt and equity
	Interest rate risk increases during lifetime of loans	Sponsors	Hedging - mostly mandatory in Project Finance
	Inflation risk	Off-taker	PPA tariff escalated with inflation rate, or anticipation of inflation rate over PPA lifetime (LCOE approach)
		Sponsor	in fixed PPA tariff, risk falls to dividends/equity
Political & Sovereign risk	Changes in law, expropriation	Political Risk Insurance	Political Risk Insurance like OPIC, DIA, Export Credit Agencies (Hermes etc.) and/or Multilateral Development Agency involved (World Bank, Asian Development Bank et.)
	Restricted transfer of	Sponsors	Political Risk Insurance for Equity

	Dividends		
	Expropriation	Sponsors	Political Risk Insurance for Equity
Force Majeure	Earthquake, Tsunami, Thunderstorm, Sand-storms.	Insurance or PPA Off-taker	Force Majeure Insurance or regulation/stipulation in PPA

Appendix E: Analysis of rain fall data for last 50 years

Per day rain fall (mm/day) data collected from 1 April 1965 to 31 December 2016 from BWDB and analysed and forecasted for coming 25 years (project life).

Sample of collected data:

District	Station	Station_ID	DATE	Rainfall(mm)
Feni	Feni	CL358	01-apr-1965	1.30

Following are the result of the regression analysis of the last 50 years' and forecasted 25 years' data:

Average	7.56	mm per day
Standard Deviation	17.97201	-
Sample Size	27605	-
Confidence Cofficienct.	1.96	-
Margin of Error	0.212011	-
Upper Bound	7.77	mm per day
Lower Bound	7.35	mm per day
Maximum Rain fall	**280.20**	mm per day
Minimum Rain fall	0.00	mm per day
Range	280.20	mm per day
Maximum possible rain fall (continuously for 4 days without pumping)	1120.8	mm per 4 days

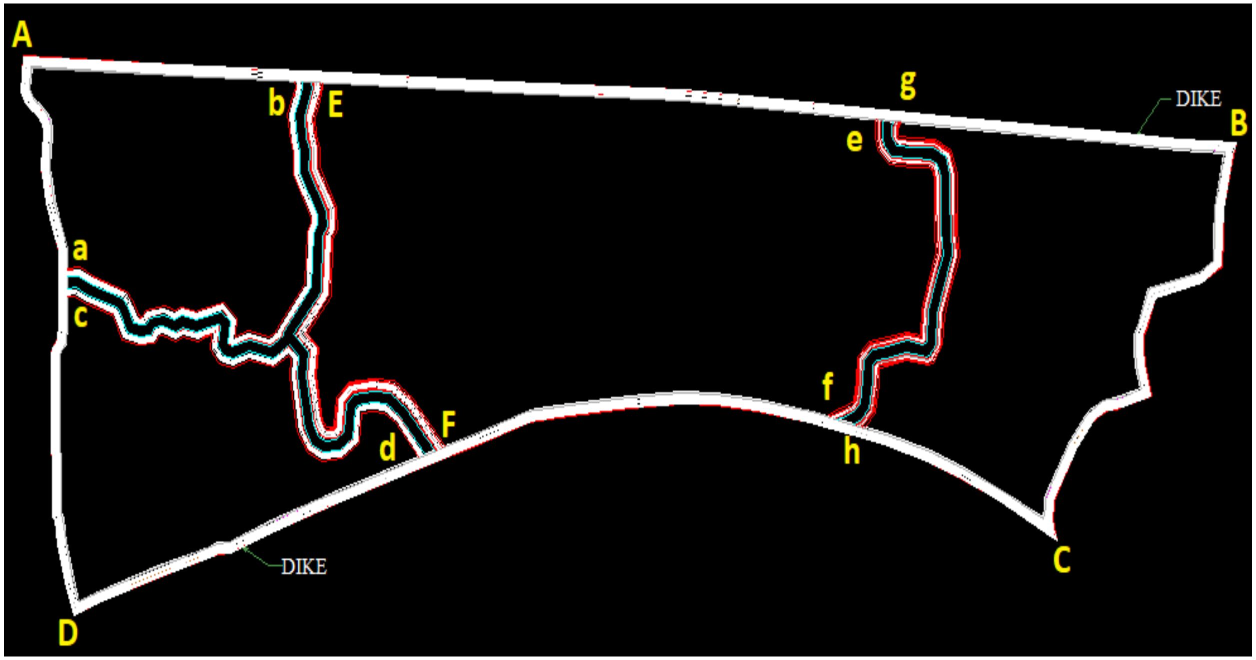
Appendix F: Assessment of Pumping Requirement

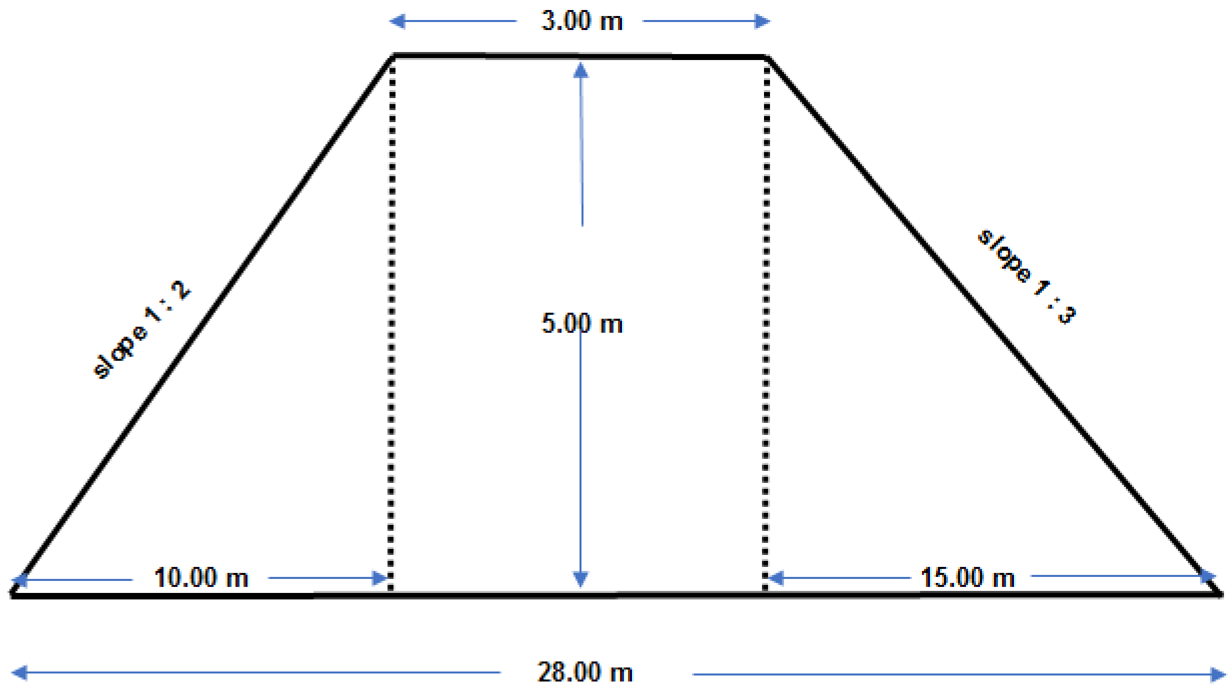
Following is the results of the assessment of the pumping requirement for pump out the collected rain water from the site, it is an indicative for this feasibility study considering over entire 1000 acres of land.

Parameter	Value	Unit	Source
Total project area	4047000	m2	Survey
Maximum Rain fall	0.0125	m/hour	Assumed maximum 300 mm per day rain fall in Feni area (as per data provided by BWDB-280.20 mm in a day of 13th May 1984 was the highest recorded historic rain fall in a day)
Water collection from rainfall in the site	50587500	lit/hour	calculated
Number of Pumps required to discharge the collected water in the site at the same rate of the maximum hourly rain fall, to maintain the balance of the site	380	Number	calculated
Electricity consumption to run the pumps	816	MWh/year	Assumed that, this much heavy rain may lasts for 4 days continuously in a year.
Cost of Pumps	1.10	m USD	Considered from the Bangladesh scheduled rate of pumps, @ 233789.3 BDT for 30 HP motor pump set
Selected pump	-	Non Clog Mud Pump	http://www.mudpump.in/mud-pumps/non-clog-mud-pump/
Suction lift up to	7.5	m	
Head	6 to 76	m	
Capacity	37	lit/second	
Power Rating	30	HP	
Power Supply	3	Phase	
Voltage Fluctuation	300 to 440	Volts	

Appendix G: Assessment of Dike Design

Following is the proposed Dike layout and dimensions:





DIMENSION OF DIKE

Following tables show the required earth soil and stone quantity with cost:

1. Dike Earth Cost

PHASE	LENGTH	VOLUME		COST		TOTAL COST
Phase - 1	5.50 km	426250.00 cu. meter	=	279,161,781.25৳	=	305,882,721.25৳
	3.40 km	40800.00 cu. meter	=	26,720,940.00৳		$3,673,826
Phase - 2	6.90 km	534750.00 cu. meter	=	350,221,143.75৳	=	369,255,883.95৳
	2.42 km	29064.00 cu. meter	=	19,034,740.20৳		$4,434,973

2. Stone Boulders Cost

PHASE	=	K.M.	QUANTITY		TOTAL QUANTITY		TOTAL COST
Phase - 1	=	5.5 km	31455.35384	=	36016.93 cu. m	=	229,069,066.65৳
	=	3.4 km	4561.578674	=		=	$2,751,250
Phase - 2	=	6.9 km	32729.57378	=	35976.34 cu. m	=	228,810,925.23৳
	=	2.4 km	3246.770703	=		=	$2,748,149

3. Sluice Gate Construction Cost

PHASE	COST IN TAKA	COST IN USD
Phase - 1	31,859,221.21৳	$382,647
Phase - 2	15,507,650.65৳	$186,256

4. Labour Cost

PHASE	LENGTH	LABOUR COST		
PHASE - 1	8.9 km	55,623,891.04৳	=	$668,075
PHASE - 2	9.3 km	58,123,841.20৳	=	$698,100

5. Cost of Road on Dike

PHASE	=	K.M.	Total volume [Width = 3.0 m]		Cost per cubic meter for Concrete		TOTAL COST
Phase - 1	=	5.5 km	4950.00 cu. m	=	6752.51 taka / cu. m	=	59,164,938.46৳
	=	3.4 km	3060.00 cu. m	=	6752.51 taka / cu. m	=	36,574,689.23৳
					95,739,627.69৳	=	**$1,149,887**
PHASE	**=**	**K.M.**	**Total volume [Width = 3.0 m]**		**Cost per cubic meter for Concrete**		**TOTAL COST**
Phase - 2	=	6.9 km	6210.00 cu. m	=	6752.51 taka / cu. m	=	74,225,104.61৳
	=	2.4 km	2178.00 cu. m	=	6752.51 taka / cu. m	=	26,032,572.92৳
					100,257,677.53৳	=	**$1,204,152**

Following table shows the total cost of the Dike construction:

Total Cost of Dike Construction for entire project boundary of 10.8 KM (including material, labour, civil work, sluice gate etc.)	**BDT**	=	1,788,156,608
	Million USD	=	21.5

Note: *This Dike design, assessment and costing is based on available public data and details for Bangladesh, further there is need of detailed study on Dike use, design and costing during vendor engineering.*

Appendix H: Analysis of last 50 years Surface Water Level (Flooding)

Following three meteorological measuring stations' last 50 years data were collected for the analysis from BWDB:

District	RiverID	RiverName	StationID	StationName	TypeCode	Latitude	Longitude	Upazila	Elevation of measuring station	Elevation of the site boundary	Difference in Elevation
Chittagong	38	Feni	SW86	Dhumghat	TDWL	22.9091	91.50	Mirsharai	6m	7m	-1m (Measuring Station is 16.32 Km from the North-East corner of the site)
Chittagong	38	Feni	SW87	Sonapur	TDWL	22.8914	91.49	Mirsharai	8m	7m	1m (Measuring Station is 14.15 Km from the North-East corner of the site)
Noakhali	69	Little Feni Dakatia	SW182	Companyganj	TDWL	22.8883	91.35	Companiganj	7m	7m	0m (Measuring Station is 10.43 Km from the North-West corner of the site)

Companyganj station is at same elevation of the project site (both are 7 m above MSL, on an average, based on GIS mapping). The data of Companyganj station for last 50 years has been analysed and forecasted. Following table shows the result of the analysis:

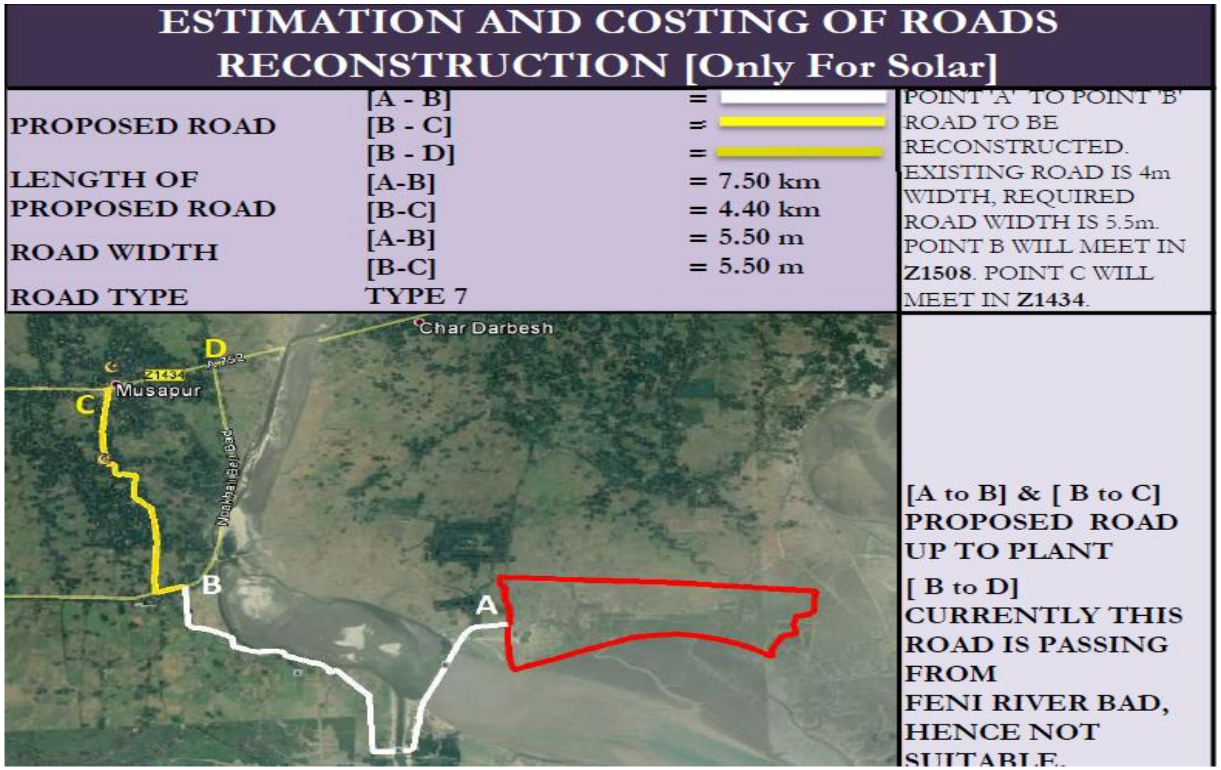
Average	3.97	m
Standard Deviation	2.264982	-
Sample Size	790	-
Confidence Cofficienct.	1.96	-
Margin of Error	0.157946	-
Upper Bound	**4.13**	m
Lower Bound	3.81	m
Max	51.74	m
Min	1.44	m
Range	50.30	m

Occurrence of maximum storm surges in the past:

Date	Region	Event	Source
1961, May 6-9	Meghna estuary (landfall near Feni river)	Severe cyclonic storm, w=145 km/h, s=4.5m and t=1.2m at Galachipa.	CYCLONE HAZARD IN BANGLADESH - By Sirajur Rahman Khan Revised by Michiel Damen, ITC (http://www.adpc.net/casita/Case_studies)
1962, October 26-30	Feni-Chittagong coast	Cyclonic storm, w=200 km/h, s=5.8m and t=0.0m.	
1983, October 15	Chittagong-Feni coast (landfall near Chittagong)	Cyclonic storm, w=122 km/h.	

Appendix I: Proposed approach road

Following image shows the proposed approach road for the site (considering the proposed bridges and culverts):



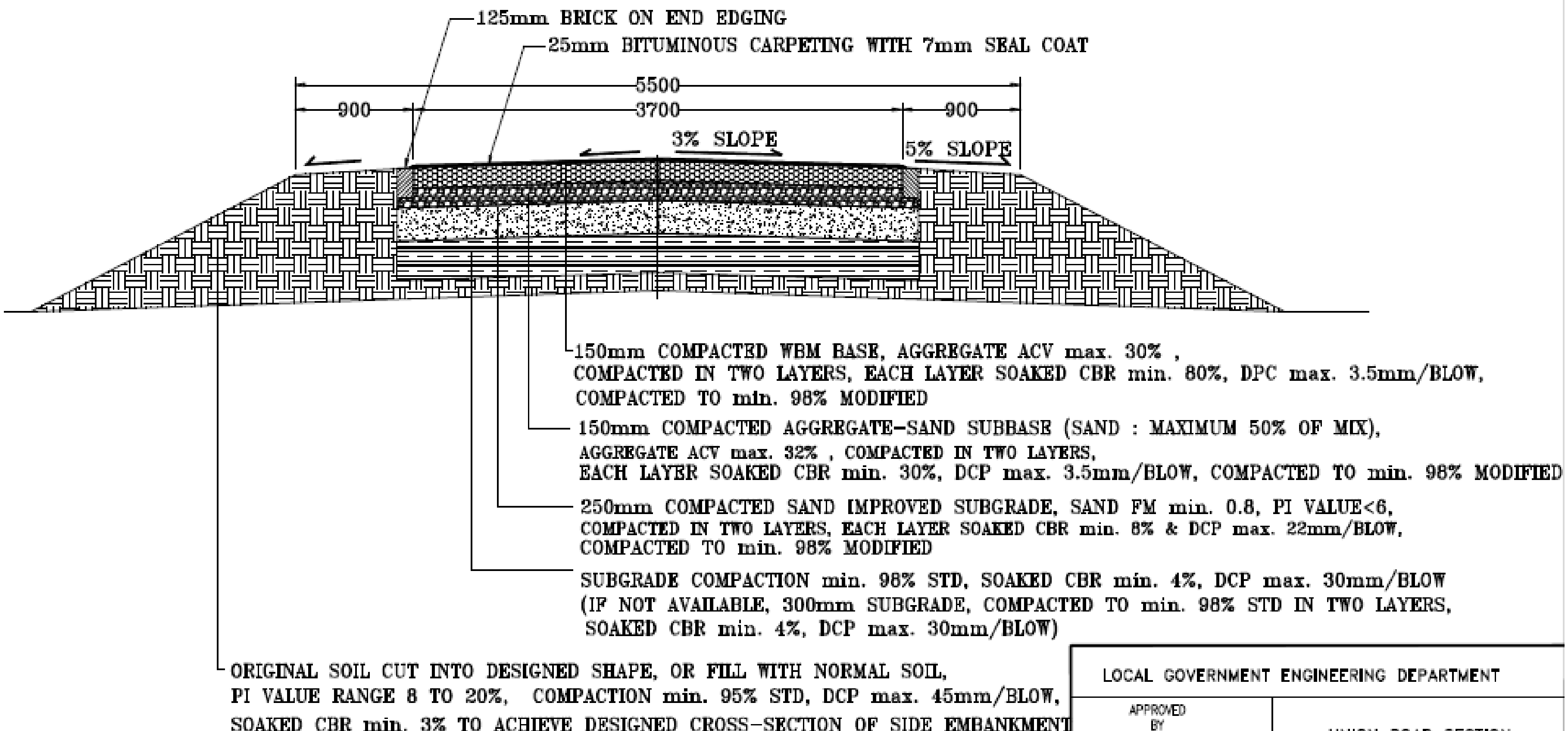
TOTAL COST IN RECONSTRUCTION OF ROAD

ROAD					
NAME	LENGTH	WIDTH	AREA	REMARK	
A - B	7.50 km	5.50 m	41250.00 sq. m	*PROPOSED ROAD*	
B - C	4.40 km	5.50 m	24200.00 sq. m		
NAME	LENGTH	TYPE	COST / km (LAC TAKA)	TOTAL COST (LAC TAKA)	REMARK
A - B	7.50 km	TYPE 7	31.8	274.275	*WE HAVE CONSIDERED COST AND TYPE OF THE ROAD FROM "ROAD DESIGN STANDARD" "GOVERNMENT OF THE PEOPLES REPUBLIC OF OF BANGLADESH PLANNING COMMISSION" DATED MAY 2004.*
B - C	4.40 km	TYPE 7	31.8	160.908	*FOR CURRENT SENARIO WE HAVE ASSUMED 15% ECCELARATION FACTOR OVER THE CONSIDERED (COST/ km).*

TYPE - 7 Road Cross Section is mentioned in the next page.

UNION ROAD SECTION

DESIGN TYPE 7



LOCAL GOVERNMENT ENGINEERING DEPARTMENT		
APPROVED BY	UNION ROAD SECTION (ROAD TYPE 7)	
	PROCESS	DESIGN UNIT
MD. SHAHIDUL HASSAN CHIEF ENGINEER	DRAWING NO	UNR-07-2A

DRAWING PLATE UNR-BC2-SL-2A

Appendix J: Solar PV plant maintenance schedule

SN	Inspection	Actions required	Inspection frequency
A	**Solar Modules**		
1	Dust deposition	Cleaning of modules	About 15 Days Average
2	Module Junction box malfunction, visual inspection	Dust Cleaning; Replace the Module junction box in case of failure.	1 Month
3	Improper Module Cable Connectors	Replace the Cables / Connectors	1 Month
4	De-lamination, discoloration leading to low output	Replace the Module	As and when required
5	Module Cracks	Replace the module	As and when required
B	**Solar Module Mounting Structure**		

	Inspection of Mounting Structure and Hardware	Check Fasteners - take remedial measures in case of issues. Check lugs of earthing conductors for corrosion – change as needed	3 Months
C	**Inverter (Input) Technical Parameters**		
1	DC Voltage @ Connection Point		3 Months
2	SSM Current @ Connection Point		3 Months
D	**Inverter**		
1	Loose cable Termination	Tighten the connection	6 months
2	Dust Deposition	Cleaning	Monthly
3	Cleaning of Air Filters	Cleaning	Monthly
4	Performance monitoring	Visual	Daily
5	Data Logging		Daily
6	Report preparation		Monthly

E	**Inverter (Out Put) Technical Parameters**		
1	Output Voltage		3 Months
2	Current		3 Months
3	Frequency		3 Months
4	Output Power		3 Months
F	**LV Panel**		
1	Loose cable Termination	Tighten the connection	6 months
2	Schedule maintenance as indicated by LV Panel Supplier		
3	Dust Deposition	Cleaning	Monthly
4	Performance monitoring		Daily
G	**LV Panel (Out Put) Technical Parameters**		
1	Voltage		Monthly

2	Current		Monthly
3	Frequency		Monthly
H	**Transformer**		
1	Schedule maintenance as indicated by Transformer Supplier		
2	Dust Deposition	Cleaning	2 months
3	Performance monitoring		Daily
I	**Transformer (Out Put) Technical Parameters**		
1	Voltage		Monthly
2	Current		Monthly
3	Frequency		Monthly
J	**MV Panel (Out Put) Technical Parameters**		
1	Voltage, Frequency		2 months

K	**Emergency Break down**		As and when required
L	**Spare parts**	Ensure availability of spare parts as required for the plant to run normally. (Only Supply of spares for free issue material is in JPL's scope, provided that list of spares required is provided by operator well in advance)	1 months
M	**Irradiance Meter cleaning**	Cleaning with soft cloth	Daily
N	**Cable (AC & DC)**	Visual inspection	15 days
O	**SCADA**	Data Monitoring	Daily

Appendix K: Cost of Foundation and Structure

For 1.5 meter system with Dike

Solar PV Structure Cost

	Assumed Kg/KW	Total Capacity (MW_{dc})	Total Weight Super Structure (Tons)	Cost Per Kg (Taka)	Total Cost
Phase-1	65	68.038	4422.47	106.12৳	469,312,516.40৳
Phase-2	65	166.01	10790.65	106.12৳	1,145,103,778.00৳
			SUB TOTAL-1		1,614,416,294.40৳

Solar PV Structure Foundation Cost

Single Table									
No. Of Columns	No. Of Piles	Pile			Total Volume (M^3)	Reinf	Cost		Total
		Dia(Mm)	Above Ground(Mm)	Depth (Below Ground)(Mm)		M	Concrete	Reinforcement	Cost
16	16	300	1000	4500	6.220				

Total Capacity (Mw_{dc})	No. Of Modules Per Table	Capacity Of Table (Kwp)	Total Tables	Total Piles	Volume Of Of Concrete In One Pile(M^3)	Total Volume Of Concrete (M^3)	Total Weight Of Reinforcement Required (Kg)	Cost Of Concrete Per Cubic Metre	Cost Of Reinforcement	Total Cost

	68.038	60	18.9	3600	57598	0.388772091	22393	447852.2839	6,752.50৳	52.00৳	174,494,446.12৳
	166.01	60	18.9	8784	140538	0.388772091	54637	1092741.669	6,752.50৳	52.00৳	425,759,472.67৳
									Sub Total-2		600,253,918.79৳

Power Transformer Foundation Cost

Power Transformer at 1.5m		**Cost in BDT**
Total Cost Power Transformer Foundation		7,199,899.06৳
Total Cost including Miscellaneous	Machinery Transportation	8,639,878.87৳

Inverter Block Foundation Cost

Inverter Foundation At 1.5 M Height			
Total No. Of Foundation [Location=43]		Phase - 1	25
		Phase - 2	62
Cost Of Foundation In One Area		Phase - 1	422,643.1৳
		Phase - 2	422,643.1৳
Total Cost Of Foundation		Phase - 1	10,566,076.25৳
		Phase - 2	26,203,869.10৳
Total Cost Of Foundation Including Miscellaneous	Machinery	Phase - 1	12,679,291.50৳
	Transportation	Phase - 2	31,444,642.92৳

For 5 meter system without Dike

Solar PV Structure Cost

	Assumed Kg/KW	Total Capacity (MW_{dc})	Total Weight Super Structure (Tons)	Cost Per Kg (Taka)	Total Cost
Phase-1	245	68.038	16669.31	106.12৳	1,768,947,177.20৳
Phase-2	245	166.01	40672.45	106.12৳	4,316,160,394.00৳
			Sub Total -1		6,085,107,571.20৳

Solar PV Structure Foundation Cost

Single Table										
No. Of Columns	No. Of Piles	Pile		Pile Cap (Thk.-500mm)		Total Volume (M^3) Of Concrete In Single Structure	Reinf	Cost		Total
		Dia(Mm)	Depth(Mm)	Length (Mm)	Breadth (Mm)		M	Concrete	Reinforcement	Cost
12	24	500	5000	2000	1000	35.55				

Total Capacity (MW_{dc})	No. Of Modules Per Table	Capacity Of Table (KWp)	Total Tables	Total Piles	Volume Of Concrete In One Pile(M^3	Total Volume Of Concrete (M^3)	Total Weight Of Reinforcement Required (Kg)	Cost Of Concrete Per Cubic Meter	Cost Of Reinforcement	Total Cost

Phase-1	68.038	300	94.5	720	17279	2.9625	51190	1023809.905	6,752.50৳	52.00৳	398,901,934.14৳
Phase-2	166.01	300	94.5	1757	42161	2.9625	124903	2498055.238	6,752.50৳	52.00৳	973,304,772.14৳
									Sub Toatal-2		1,372,206,706.29৳

Power Transformer Foundation Cost

Power Transformer at 5.0 m		Cost in BDT
Total Cost of 4 Power Transformer with embankment		17,909,559.93৳
Total cost including miscellaneous	Machinery Transportation	21,491,471.91৳

Inverter Block Foundation Cost

Inverter Foundation At 5.0 M Height		Cost in BDT	
Total No. Of Foundation [Location=43]		Phase - 1	25
		Phase - 2	62
Cost Of Foundation In One Area		Phase - 1	157,223.2৳
		Phase - 2	157,223.2৳
Total Cost Of Earthwork And Stone Pitching		Phase - 1	67,706,192.0৳
		Phase - 2	167,911,356.2৳
Total Cost Of Foundation		Phase - 1	71,636,772.37৳
		Phase - 2	177,659,195.47৳
Total cost including miscellaneous	Machinery	Phase - 1	85,964,126.84৳
	Transportation	Phase - 2	213,191,034.56৳

Appendix L: Solar Resource Data Assessment Study

Note: provided separately due to large file.

Appendix M: Wind Resource Data Assessment Study

Note: provided separately due to large file.

Appendix N: Resource Data

Note: provided separately due to large file.

Appendix O: Hydrology Data

Note: provided separately due to large file.

Appendix P: Financial Model

Note: provided separately due to large file.