ISTANBUL TECHNICAL UNIVERSITY

SHIPBUILDING AND OCEAN ENGINEERING MASTER DEGREE

WIND TURBINE DESIGN

DEVELOP AN OFFSHORE WIND FARM AROUND THE ISLAND OF LUZON / PHILIPPINES

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Contents

Abbreviations

E: Energy of wind (Watt)

P: Power of wind (Watt)

V: Wind Speed(m/s)

A: Rotor Area(m2)

p: Air Density (kg/m3)

m: Meter

T: Temperature

R: Specific gas constant for dry air

W: Watt

MW: Megawatt

KW: Kilowatt

G: Acceleration of Gravity

U: Wind Speed(m/s)

Hf: Height of Fully Formed Wave

Λ: Dimensionless of Coefficient

h: Height of Wind Speed Point

href: Reference Height for Measured According to Wind Speed

z: Altitude of Wind Speed

EPC: Engineering, Procurement and Construction Agreements.

PPA: Power Purchase Agreements.

REC: Renewable Energy Agreements.

O&M: Operation and Maintenance Agreements.

PPA: Philippines Port Authority. This Agreement includes

DTI: Department of Trade and Industry

DLE: Department of Labor and

PCG: Philippines Coast Guard Service for protection of Project Areas

NGCP: National Grid Corporation of Philippines

CAPEX: Capital Expenditure

OPEX: Operation Expenditure

AEP: Annual Energy Production

COE: Cost Expenditure

CP: Capacity Factor

HH: Hub Height

OHH: Optimum Hub Height

Figures

Foreword

I tried to examine the possible offshore wind turbine installation areas in the Luzon region, Philippine from all aspects. I would like to express my thanks to Prof. Serdar Beji and Mr. Uwe Lützen for their backing. And also special thanks to Meteoblue AG team whom helped to me about wind history data.

January 2022 Begüm TÜRKÖZÜ Civil Engineer

Purpose

This report has been prepared in order to examine the location selection, installation and financing stages of offshore wind turbines in the Philippine Luzon region according to external and internal parameters.

1. Introduction

Wind turbines, they are systems that first convert the kinetic energy of the wind into mechanical energy and then into electrical energy. A wind turbine consists of a generator, speed converters (gear box), tower, electrical electronic elements and blades. In order for the efficiency of wind turbines to be high, wind turbines that are suitable for the terrain characteristics, wind speed and intended use should be selected.

Wind turbines are divided into two as Offshore and Onshore wind turbines, depending on where they are installed. Onshore wind farms which are large installations of wind turbines located on land and offshore wind farms which are installations located in bodies of water. In comparison, Onshore wind farms are most popular but nowadays offshore wind farms have more potential to generate electricity. Because there is more wind power in sea due to annual average wind maps. Thus, more energy can be produced. It is also convenient for installing larger capacity wind turbines, even if the offshore wind turbine parts are difficult to transport. Because there is no obstacle in front of you while transporting.

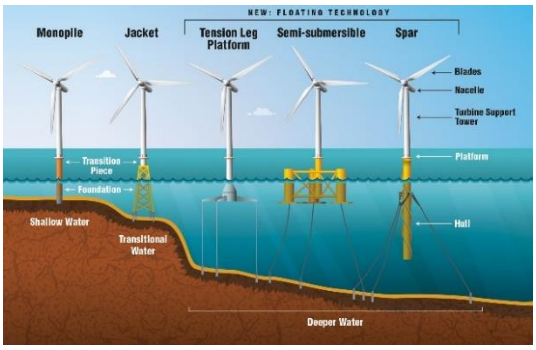

Figure 1 Foundation types of Offshore Wind Turbines

There are main selection criteria and many sub-selection criteria to be considered during the suitable location for offshore wind turbines.

Selection criteria are divided into two as internal and external. Internal conditions wind speed, bathymetry (water depth), distance of grid connection points, waves, size of wind farm, air density, financial plan, foundation plan, logistic plan. And external criteria are determined as grid connections, shipping routes, sea life, restrictions (e.g., tourism), borders. Making use of the wind atlases made to determine the possible regions in the selection of the appropriate location will facilitate the design phase.

The region designated for the installation of open wind turbines is the Philippine Luzon region. The Philippines is an archipelago country in Southeast Asia, that is located within the “Typhoon Alley of the Pacific.” The Philippines' proximity to the Asia-Pacific monsoon belt and its high wind capacity makes it ideal for installing wind turbines.

2. Wind Speed of Philippines Location

Many studies are examined, it is seen that wind speed is the first determining criteria to choose a suitable location. The annual average wind speed map was examined in the determined Luzon region. Flagged locations indicates the highest average wind speed.

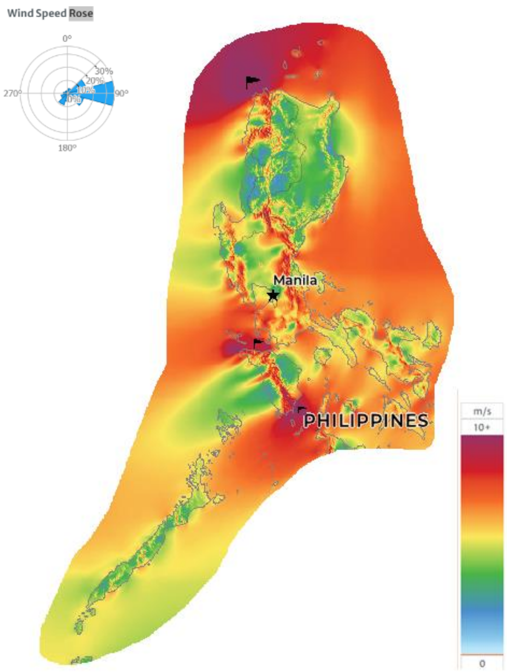

Figure 2 Wind Speed Map of Luzon, Philippines

1- Bangui Bay

2- Verde Island Passage (North side of Palauan)

3- Bulalacao Bay

For a wind turbine to work efficiently, it is accepted that the average wind speed is above 7 m/s, but wind energy is captured at these levels. Flagged regions meet this value. However, the minimum working wind speed of the selected wind turbine model should be analyzed for the installation site in the next examinations. Wind speed affects the capacity factor. Increasing the capacity factor increases energy production.

On the other hand, it is possible to confirm the importance of wind speed parameter with the wind energy equation.

$$\grave{E}=P=\frac{1}{2} * \rho * v^3 * A \quad (W)$$

E: Energy of wind (Watt)
P: Power of wind (Watt)
V: Velocity of wind(m/s)
A: Rotor Area(m2)
p: Air Density (kg/m3)
With **V** in the 3rd. potential that means double wind speed = **8 times more** energy. The greater the wind speed, the wind power will be affected by **3 times** the wind speed. Thus, the wind turbines to be installed will use high wind energy efficiently and convert it to mechanical energy and provide electricity.

3. Grid Connection of Philippines Location

An electrical grid is a network of transmission lines, usually to distribute electric power from producers to consumer. Electrical grids vary in size and can cover whole countries or continents. So, in wind turbines, grid lines must be connected to bring the energy obtained from the wind to the consumer.

Electricity from the wind turbine generator travels to a transmission substation where it is converted into extremely high voltage, between 155,000 and 765,000 volts, for long distance transmission on the transmission grid.

For offshore wind farms however, this option is not available as a large part of the distance to the connection point necessarily must be covered by a submarine cable. The distances can be considerable, depending on local conditions, water depth and bottom conditions in particular.

The costs for grid connection can be split up in two. The costs for the local electrical installation and the costs for connecting the wind farm to the electrical grid. The way to reduce costs is to minimize the distance of the decided area for the installation of turbines.

Figure 3 Grid Line Corridors of Luzon

There are 3 main grid lines of Philippines.

1- Luzon Grid Line (Available Capacity 14763 MW at 23.12.2021)

2- Visayas Grid Line (Available Capacity 3009 MW at 23.12.2021)

3- Mindao Grid Line (Available Capacity 3346 MW at 23.12.2021)

Existing grid lines are suitable for installation in connection with the studied regions and in terms of proximity.

4. Water Depth of Philippines Location

The most basic factor that will determine the foundation type to be applied in open seas is the depth condition. Too deep water increases the cost for foundations and too shallow water makes construction difficult due to limited access for barges. And also, the cost of foundation for offshore wind farms increases significantly as the depth of sea increases from shallow waters to deep waters.

According to the stated reasons, water depth is an important parameter in terms of foundation selection, logistics and cost. Bathymetry maps should be examined to determine the depth situation.

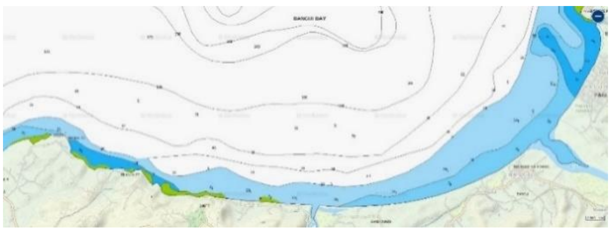

Figure 4 Water Depth in Bangui Bay, Luzon

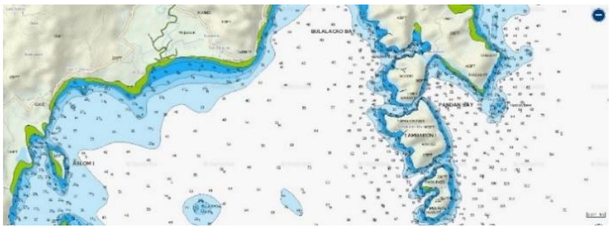

Figure 5 Water Depth in Verde Island Passage, Luzon

Figure 6 Water Depth in Bulalacao Bay, Luzon

The depths of 3 possible regions determined according to the maximum average wind speed were examined.

1- Bangui Bay

2- Verde Island Passage (North side of Palauan)

3- Bulalacao Bay

The depth of sea is classified as shallow waters (0–30 m), transitional waters (30–50 m), and deep waters (50–200 m).

In shallow waters, gravity type and monopile type foundations are used commonly. Monopile type foundation is used most commonly rather than the gravity type foundation. Gravity type foundation is expensive to construct in sea depths beyond 10m. In sea depths more than 10m, a monopile type foundation and a multipod type foundation are commonly constructed. Multipod includes both tripod and jacket combination. Multipod type foundations are generally preferred in sea depths beyond 30m in order to minimize the foundation cost.

5. Air Density of Philippines Location

For wind turbines, air density calculation is as important as wind speed. Because after the calculation of the energy to be produced, the production estimate at each turbine point is updated according to the air density, or the air density can be recalculated according to the wind power curve.

$$È = P = ½ * ρ * v^3 * A \quad (W)$$

E: Energy of wind (Watt)
P: Power of wind (Watt)
V: Velocity of wind(m/s)
A: Rotor Area(m2)
p: Air Density (kg/m3)

As seen in the formula, energy production is directly proportional to density and affects its value.

And air density account:

$$\rho_{dry\ air} = \frac{p}{R.T}$$

Where:

$\rho_{dry\ air}$ = Density of dry air (kg/m^3)

p = air pressure (Pa)

R = Specific gas constant for dry air, 287.05 J/ (kg.K)

T = Temperature (°K)

Air density is directly proportional to temperature, humidity and air pressure. Energy production is calculated again with the obtained value.

6. Waves and Directions of Philippines Location

Wave height is also one of the most important parameters to consider when choosing the Foundation type. By calculating the wind measurement values at sea level, the wave heights of the winds can be estimated. As the Wind Speed increases, the Wavelength increases. Because the winds blow from the sea surface and raise the water and create a rotational movement.

At the same time, the farther from the shore the distance the wind blows, the higher the waves will be. Thus, it becomes clear how strong the fixing joints for the foundation of open wind turbines must be in terms of strength.

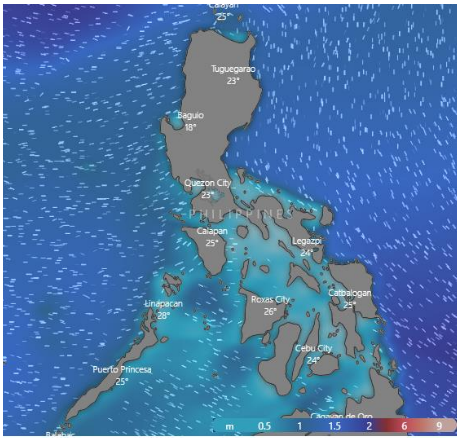

Figure 7 Wavelength of Luzon

According to wave height map, it seen that wherever the wind speed is high in the Luzon region, the wave height is also large.

If the place to be chosen is affected by the wave height, in other words, if its strength in terms of strength will be negatively affected, terminators can be used as a solution. Terminators run perpendicular to the direction the waves come from. They capture the power of the wave and send it back. Floating versions of wave terminators have also been designed for offshore applications.

Figure 8 Wave Blockers Examples

7. Shipping Routes of Philippines Location

The seas are busy areas in terms of maritime transport, ports, mining (including pipelines), electricity generation (electrical cables), armament, fishing and tourism sectors. This situation is important for the installation of wind turbines.

Sufficient sea area is required during the installation phase of offshore wind turbines (Distribution of wind turbines). For this reason, turbines are likely to be directly affected by Shipping routes. It should not be established in places with shipping routes in order not to hinder existing businesses and to have the necessary space for construction operations, transportation and maintenance stages.

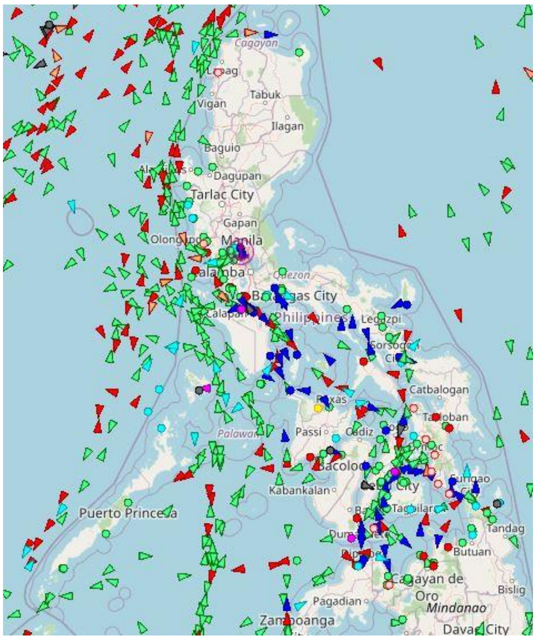

Figure 9 Shipping Routes and Active Traffic of Luzon

Considering the selected regions with high average wind speeds, it was observed that the shipping routes were affected by the shipping routes at the Verde Island Passage and Bulalacao Bay locations and the sea routes are busy. For this reason, it is an obstacle for the installation of wind turbines.

As a result of the examinations, it is seen that Bangui Bay is the most dominant location for wind farm among the 3 possible regions according to the wind speed.

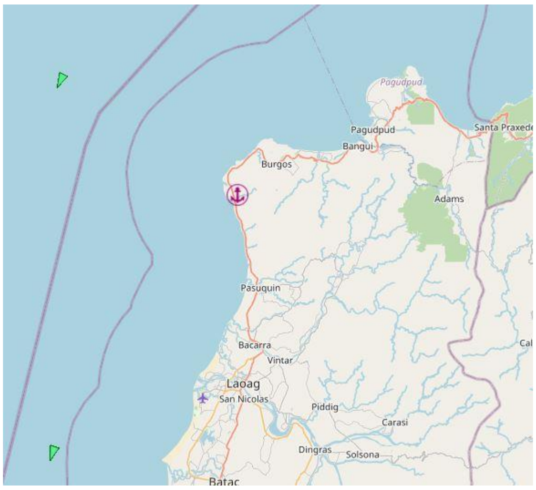

Figure 10 Shipping Routes and Active Traffic of Bangui Bay

8. Sea Life of Philippines Location

The islands of the Philippines have an impressive range of marine life, making them popular with divers worldwide. Nearly one million square miles of sea make up the waters around the country, and much of it lies in the Coral Triangle, an area containing the world's highest coral diversity.

These waters contain over 2,500 species of fish and over 500 coral species, making the Philippines a marine biodiversity hotspot. At the same time, six out of seven endangered sea turtle species call the Philippines home.

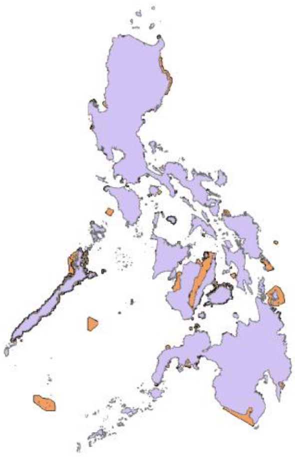

Figure 11 Marine Conservation areas in Luzon Location (Orange Points)

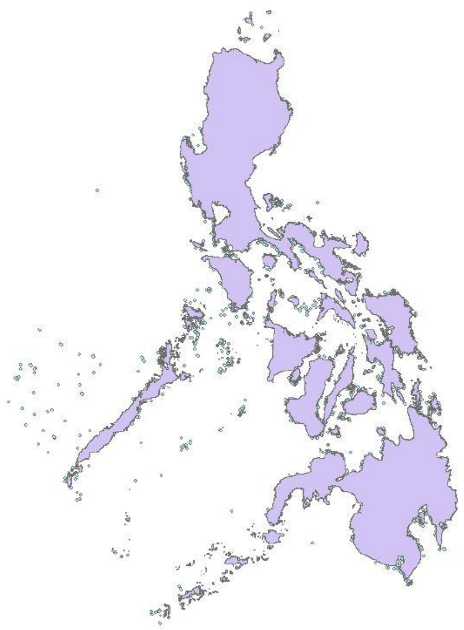

Figure 12 Coral Reefs Area in Luzon Location (Showed with Points)

According to "Techno-Economic Assessment of Offshore Wind Energy Philippines" Article 2021 there are no marine conservation area and coral reefs area in Bangui Bay.

If there was a coral reefs area in Bangui Bay, the solution would be to create an artificial reef area.

9. Restriction of Philippines Location

There are limiting conditions or precautions during the installation, maintenance, and operation of wind turbines.

- Located within the military forbidden zone and training-shooting area, hinder maritime traffic and sea border. Installation in the selected region does not constitute a violation.
- Borders: China, Indonesia, Japan, Malaysia, Palau, Vietnam are sea borders of Philippines. These borders have agreements which creates a boundary that separates all applicable maritime jurisdiction permitted under international law, including the territorial sea, fishing, continental shelf, and any other rights permitted in the exclusive economic zone. So, existing sea borders specified do not constitute an obstacle for the wind turbine area to be established.
  In addition, the determined wind turbine location is not close to the border regions

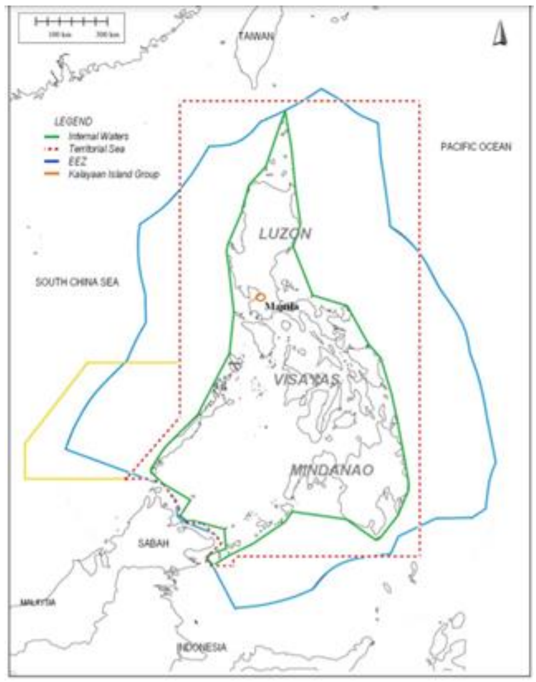

Figure 13 Maritime Zones of Philippines

Figure 14 Sea Borders of Philippines

According to Birdlife International Organizations, there are no restricted range area for bird life in Bangui Bay. Restrictions and protections are available only for the following regions:

- The Cordillera Central
- The Zambales Mountains
- The Sierra Madre

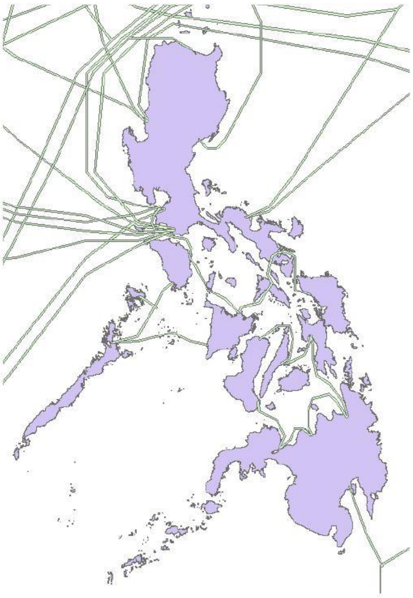

Figure 15 Submerged Loss in Luzon Location (Orange Points)

According to "Techno-Economic Assessment of Offshore Wind Energy Philippines" Article 2021 there are no submerged cable within **2 km** at Bangui Bay. So, Bangui Bay is suitable selection to establish wind farm.

- Soil and Gas extraction areas

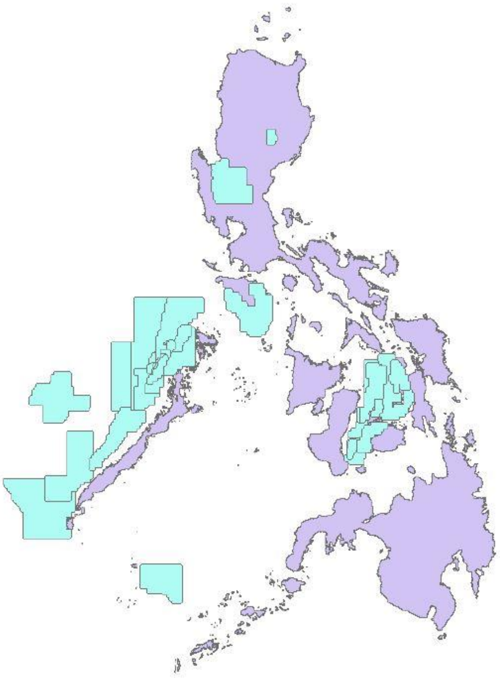

Figure 16 Soil and Gas in Luzon Location (Blue Points)

According to "Techno-Economic Assessment of Offshore Wind Energy Philippines" Article 2021 there are no soil and gas extraction area in Bangui Bay.

10. Bangui Bay

Figure 17 Bangui Bay

According to parameters above, Bangui Bay will be the optimum choice.

Bangui Bay is located north side of Luzon. It has a population of 15,019 people according to 2020 census. Bangui is 554 kilometers from Metro Manila and 67 kilometers from Laoag City, the provincial capital.

According to geotechnical research, soil conditions were found suitable for the installation of wind turbines.

10.1Wind Speed of Bangui Bay

According to "Meteoblue History+ data" for Bangui Between 01.01.1985-31.12.2021 average wind speed is calculated **4,6 m/s.**

Years	Average of Bangui Wind Speed [10 m]
1985	4,65
1986	4,72
1987	4,35
1988	4,58
1989	4,90
1990	4,52
1991	4,70
1992	4,37
1993	4,59
1994	4,61
1995	4,71
1996	4,90
1997	4,43
1998	4,23
1999	4,65
2000	4,76
2001	4,66
2002	4,57
2003	4,73
2004	4,79
2005	4,52
2006	4,68
2007	4,55
2008	4,76
2009	4,59
2010	4,13
2011	4,96
2012	4,53
2013	4,69
2014	4,56
2015	4,52
2016	4,15
2017	4,58
2018	4,72
2019	4,30
2020	4,61
2021	4,96
Grand Average	**4,60**

Figure 18 Annual Wind Speed Average Between 1985-2021 of Bangui Bay

The wind rose also shows that, there is variable wind speed, but the direction is almost constant.

Figure 19 Wind Rose of Bangui Bay

	Qtr1			Qtr2			Qtr3			Qtr4			Grand
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec	Average
1985	6,02	4,53	5,92	4,36	4,37	2,75	2,64	2,82	3,46	6,13	6,14	6,54	4,65
1986	6,83	5,54	5,15	4,53	3,40	2,97	3,27	3,70	3,85	5,43	5,89	6,11	4,72
1987	6,19	5,83	3,89	3,48	2,28	2,70	2,76	4,01	3,09	4,96	6,18	6,92	4,35
1988	5,48	5,74	4,47	4,48	3,15	2,46	3,74	2,36	2,57	5,75	7,27	7,49	4,58
1989	6,88	6,25	5,70	3,80	3,92	2,85	4,24	3,11	3,72	5,65	6,90	5,88	4,90
1990	6,08	5,17	5,00	3,37	3,25	2,81	2,49	4,37	3,52	5,60	6,08	6,47	4,52
1991	5,77	5,81	5,02	4,45	4,36	4,24	3,08	2,82	3,33	5,20	6,18	6,27	4,70
1992	5,53	4,75	4,12	2,77	3,13	2,45	3,63	3,12	3,68	6,13	6,52	6,55	4,37
1993	6,03	5,95	5,01	4,03	3,27	2,23	2,75	2,64	2,79	5,90	6,72	7,77	4,59
1994	5,86	5,23	6,13	4,09	2,59	2,92	3,27	3,48	3,23	5,51	6,11	6,89	4,61
1995	6,06	5,26	4,87	4,83	3,07	2,48	2,80	2,93	4,37	5,50	6,77	7,58	4,71
1996	6,68	6,67	5,27	5,26	3,16	3,33	3,40	3,10	3,82	4,63	6,49	7,03	4,90
1997	5,85	6,42	5,36	4,10	2,71	2,32	2,88	3,75	3,59	4,58	5,46	6,29	4,43
1998	5,30	4,11	5,13	3,88	3,16	2,63	2,54	2,69	3,18	5,45	5,71	6,91	4,23
1999	6,72	6,75	5,06	5,08	2,89	2,31	2,55	2,96	2,97	5,04	6,52	7,12	4,65
2000	6,39	6,11	5,80	3,72	3,47	2,73	3,35	2,47	4,37	5,86	6,08	6,77	4,76
2001	6,19	6,47	5,03	3,98	2,13	2,71	3,53	2,47	3,99	5,47	7,03	7,11	4,66
2002	5,91	6,17	4,97	5,33	3,93	2,61	3,37	2,92	2,89	4,45	6,23	6,14	4,57
2003	6,48	6,06	5,52	4,42	3,66	3,09	3,59	2,91	3,50	4,96	5,62	7,07	4,73
2004	5,85	5,92	5,09	3,76	4,27	3,98	3,17	3,32	3,42	5,33	6,97	6,40	4,79
2005	5,26	4,93	5,36	4,16	1,93	2,04	3,61	3,23	4,40	5,22	6,39	7,68	4,52
2006	5,64	6,69	4,96	3,58	3,66	3,26	3,81	3,39	3,78	4,98	5,28	7,21	4,68
2007	6,53	5,46	4,93	4,43	2,73	2,67	2,55	3,16	3,05	5,53	6,90	6,69	4,55
2008	6,42	6,80	5,65	4,85	3,03	2,53	3,24	2,57	3,27	4,68	6,73	7,43	4,76
2009	7,03	5,94	4,73	4,48	4,79	2,50	2,31	3,23	3,01	5,36	5,87	5,85	4,59
2010	6,19	3,48	5,13	3,73	2,49	1,83	2,32	2,42	3,64	5,93	6,12	6,14	4,13
2011	7,31	5,61	7,02	5,02	2,86	3,04	2,96	4,11	3,97	4,67	5,73	7,22	4,96
2012	5,86	5,80	6,23	3,19	2,11	2,87	2,82	4,07	4,48	5,49	4,95	6,47	4,53
2013	6,55	6,29	4,51	3,71	2,43	3,08	3,62	4,06	4,10	5,15	6,64	6,19	4,69
2014	6,44	5,12	5,27	4,64	2,33	1,80	3,20	3,83	3,62	5,30	5,74	7,42	4,56
2015	6,66	5,73	5,26	4,57	2,39	1,92	3,24	3,90	3,34	5,42	6,01	5,87	4,52
2016	4,53	5,71	4,49	2,80	2,07	3,07	2,47	3,52	3,18	4,92	6,14	6,99	4,15
2017	6,91	6,33	5,29	3,58	2,52	2,25	3,26	2,76	3,27	5,53	6,18	7,20	4,58
2018	6,28	5,60	5,54	5,07	3,27	2,82	2,78	3,16	3,96	5,30	6,13	6,80	4,72
2019	6,61	5,09	4,37	3,26	2,23	2,10	2,21	4,02	3,76	4,82	6,45	6,66	4,30
2020	6,02	6,42	4,59	4,84	2,49	2,32	2,27	3,28	3,27	6,20	6,91	6,73	4,61
2021	6,75	5,91	5,67	5,55	3,64	3,12	4,03	2,93	3,67	5,39	6,05	6,86	4,96
Grand Total	**6,19**	**5,72**	**5,18**	**4,19**	**3,06**	**2,70**	**3,07**	**3,23**	**3,54**	**5,34**	**6,25**	**6,78**	**4,60**

Figure 20 Annual Wind Speed Average by Quarters and Months of Bangui Bay

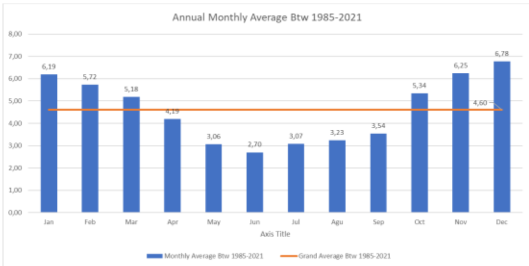

Figure 21 Annual Wind Speed Average by Quarters and Months of Bangui Bay

10.2Grid Connection

According to National Grid Connections of Philippines (NGCP), There is 230 kV Substation Center in Laoag City which is 50 km from Bangui. And also, there is existing 115kV line between Laoag City Substation Center and Bangui. This line is constructed for the Wind Farm which is located onshore Wind Farm at Bangui Bay Beach.

So even in that case, Bangui Bay location is appropriate for connection grid lines.

Figure 22 Grid Line Corridor of Luzon

According to NGCP Transmission Development Plan 2020-2040 ;

Until Jun 2024, there will be expansion on Laoag Substation Center and upgradation from **115 kV** to **230 kV** for Laoag-Bangui Transmission line.

So Bangui Bay location is in scope of investment for Wind Energy and Transmission system by goverment.

Northern Luzon 230 kV Loop	Ilocos Norte, Apayao, Cagayan	Jun 2024
	Substation Components: ▪ Laoag 230 kV Substation (Expansion), 4-230 kV PCBs and associated equipment; ▪ Bangui 230 kV Substation (New), 2x300 MVA, 230/115-13.8 kV Power Transformer and accessories, 14-230 kV PCBs, 18-115 kV PCBs and associated equipment;4x50 MVAR, 115 kV Shunt Capacitor and accessories, 4x25 MVAR, 115 kV Shunt Reactor and accessories; ▪ Sanchez Mira 230 kV Substation (New), 2x300 MVA, 230/69-13.8 kV Power Transformers and accessories, 18-230 kV PCBs and associated equipment, 8-69 kV PCB's and associated equipment; 4x25 MVAR, 230 kV Shunt Capacitor and accessories, 4x25 MVAR, 230 kV Shunt Reactor and accessories; ▪ Pudtol 230 kV Substation (New), 10-230 kV PCBs and associated equipment; ▪ Lal-lo (Magapit) 230 kV Substation (Expansion), 4-230 kV PCBs and associated equipment. Transmission Components: ▪ Laoag–Bangui 230 kV Transmission Line, ST-DC, 2-795 MCM, ACSR, 50 km; ▪ Bangui–Sanchez Mira 230 kV Transmission Line, ST-DC, 2-795 MCM, ACSR, 70 km; ▪ Pudtol–Sanchez Mira 230 kV Transmission Line, ST-DC, 2-795 MCM, ACSR, 57 km; ▪ Lal-lo (Magapit)–Pudtol 230 kV Transmission Line, ST-DC, 2-795 MCM, ACSR, 38 km. Bulk Cost Estimate: 18,102 Million Pesos	

Figure 23 NGCP Northern Luzon Expansion Date

10.3Connection to Grid Line of Bangui Bay

For Bangui Bay Wind farm project, there will only need to line between wind farm and Laoag City-Bangui Transmission line. There will be small substaion and inverter center near Bangui Beach.

Details and sketch showed on **10.10.2 Layout Section.**

10.4Density of Bangui Bay

Air density has been calculated in Bangui Bay, where the wind turbines will be installed. The average temperature of the region was found to be **26.10** Celsius.

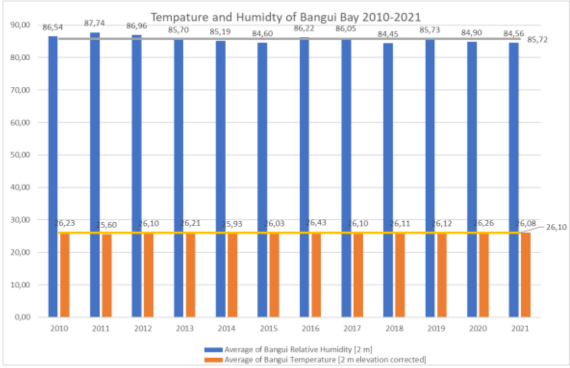

Figure 24 Temperature and Relative Humidity for last 10 years of Bangui Bay

According to "Metaoblue 10-year data's", average temperature can be founded **26,10** Celsius and relative humidity is **85,72%.**

$$\rho_{dry\ air} = \frac{p}{R.T}$$

Where:

$\rho_{dry\ air}$ = Density of dry air (kg/m^3)

p = air pressure (Pa)

R = Specific gas constant for dry air, 287.05 J/ (kg.K)

T = Temperature (°K)

So estimated dry air density can be calculated 1,18 kg/m3 for Bangui Bay.

10.5Depth of Bangui Bay

Bathymetry maps of Bangui Bay is given below.

Bangui Bay is the Ocean (open sea) bay. Therefore, water depth has too much variability.

Figure 25 Water Depth Bathymetry Map of Bangui Bay

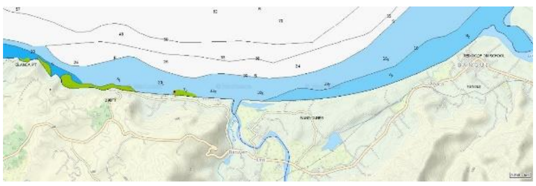

Figure 26 Water Depth Bathymetry Map of Bangui Bay

So, wind farm will be located**; 500m** from coast side and there will be only **10-30 m** water depth.

Pre sketch is given below.

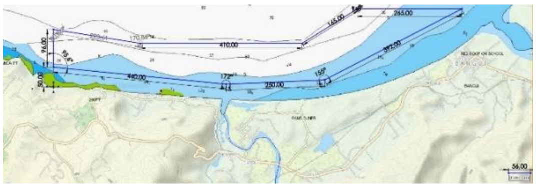

Figure 27 Appropriate Pre-sketch of Wind Farm

Based on the construction location of wind farm in the offshore regions, a suitable foundation type is required to choose for wind turbine tower in order to achieve sustainability. The selection of type of foundation for offshore wind turbine tower is governed by the sea depth.

Foundation types given below for different water depths. Bangui Bay wind farm will be nearshore, and depth will be approximately **10-30m**. So **Monopile foundation** will be enough.

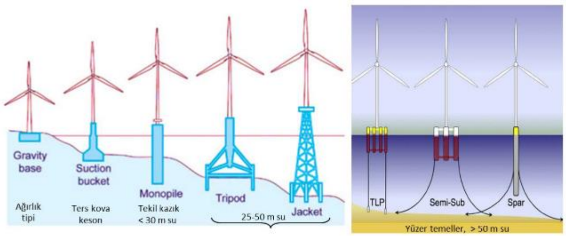

Figure 28 Foundation Types relationship between water depths

10.6Wave and Direction of Bangui Bay

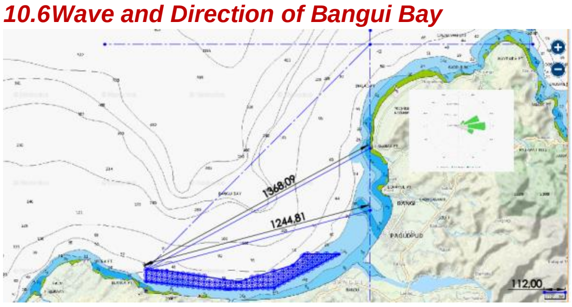

Figure 29 Fetch Distance from Installation Area to Coast According to Wind Direction

Wave height is related with the wind forecast. In above sketch, Fetch distance calculated for common wind direction. Sketch scale is **1,12km=112mm**, so **13,7km** is Maximum Fetch distance for common wind direction. According to wind speed data's there is approximately calculated wave heights below table.

Wind Speed Ranges	Wind Speed Rages Percentage	Significant Wave Height (m) from Bretschneider Emp. Rel.
0-1	1,49%	
1-2	8,33%	0,02
2-3	11,63%	0,11
3-4	10,79%	0,26
4-5	9,63%	0,46
5-6	9,78%	0,72
6-7	11,75%	1,03
7-8	13,84%	1,4
8-9	11,25%	1,84
9-10	6,31%	2,33
10-11	2,78%	2,88
11-12	1,24%	3,49
12-13	0,56%	4,15
13-14	0,28%	4,87
14-15	0,13%	5,65
15-16	0,06%	6,49
16-17	0,04%	7,38
17-18	0,02%	8,33
18-19	0,02%	9,34
19-20	0,02%	10,4
20-21	0,01%	11,5
21-22	0,01%	12,72
22-23	0,01%	13,95
23-24	0,00%	15,24
24-25	0,00%	16,58
25	0,00%	17,96
25+	0,02%	<18

Figure 30 Wind Speed Relationship with Wave Height

$$Hs = V^2 \cdot (0.283 \cdot \tanh(0.0125 \cdot ((g \cdot F)/V^2))^{0.42})/g$$

Hs= Significant Wave Height (m)
V= Wind Speed (m/s)
F= Fetch Distance (m)

So Significant Wave Height can be accepted **1 to 2,8m** for common wind speeds.

The wave direction is usually directly proportional to the wind direction.

This information can be used on Hub Calculations.

10.7Wind Speed Calculations

To select appropriate wind turbine model, wind speed must be calculated at different heights.

Equation of Wind Speed at Selected Height:

$$V(h) = V(h_{ref})\left(\frac{\ln(h / z_0)}{\ln(h_{ref} / z_0)}\right)$$

Years	Average of Bangui Wind Speed [10 m]	Average of Bangui Wind Speed at [80 m]	Average of Bangui Wind Speed at [90 m]	Average of Bangui Wind Speed at [100 m]
1985	4,65	5,70	5,75	5,79
1986	4,72	5,77	5,82	5,87
1987	4,35	5,40	5,45	5,49
1988	4,58	5,62	5,67	5,71
1989	4,90	5,99	6,05	6,09
1990	4,52	5,58	5,63	5,67
1991	4,70	5,79	5,84	5,89
1992	4,37	5,37	5,42	5,46
1993	4,59	5,69	5,74	5,79
1994	4,61	5,67	5,72	5,76
1995	4,71	5,78	5,83	5,88
1996	4,90	6,03	6,08	6,13
1997	4,43	5,46	5,51	5,55
1998	4,23	5,25	5,30	5,34
1999	4,65	5,65	5,70	5,75
2000	4,76	5,83	5,88	5,93
2001	4,66	5,70	5,75	5,80
2002	4,57	5,62	5,67	5,71
2003	4,73	5,79	5,84	5,88
2004	4,79	5,82	5,87	5,91
2005	4,52	5,54	5,59	5,63
2006	4,68	5,69	5,74	5,78
2007	4,55	5,56	5,60	5,65
2008	4,76	5,82	5,87	5,92
2009	4,59	5,61	5,66	5,70
2010	4,13	5,04	5,09	5,13
2011	4,96	6,02	6,08	6,12
2012	4,53	5,51	5,56	5,60
2013	4,69	5,72	5,77	5,81
2014	4,56	5,57	5,61	5,66
2015	4,52	5,54	5,59	5,64
2016	4,15	5,09	5,13	5,17
2017	4,58	5,62	5,67	5,72
2018	4,72	5,76	5,81	5,86
2019	4,30	5,27	5,32	5,36
2020	4,61	5,62	5,66	5,71
2021	4,96	6,00	6,05	6,10
Grand Average	4,60	5,64	5,68	5,73

Figure 31 Wind Speed Calculation at Different Hub Height

Average Wind Speeds at different heights calculated for Bangui Bay from hourly wind speed data between 1985-2021 with Weibull Distribution.

10.8Wind Turbine Model Selection

Wind power projects aim to minimize capital expenditure (CAPEX) and operation expenditure (OPEX), and to maximize annual energy production (AEP) as with other profit-oriented projects. In other words, the goal of a wind farm design is to minimize COE as a function of CAPEX, OPEX, and AEP.

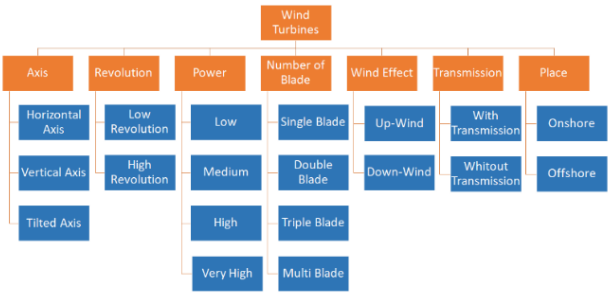

Figure 32 Wind Turbine Types

According to Meteoblue History+ data between 1985-2021, hourly wind speed values has been listed. With Weibull distribution estimated wind speed values at **100m** Height is calculated and listed by hour and hour. Thus, the most effective wind speed range was determined.

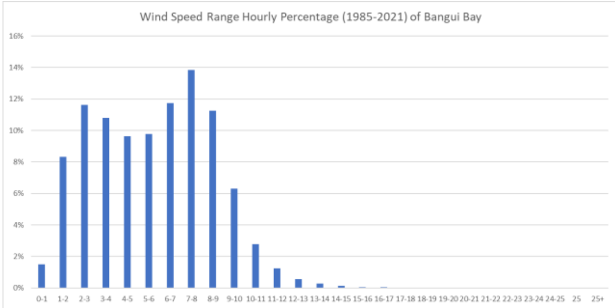

Figure 33 Wind Speed Range Hourly Percentage (1985-2021) of Bangui Bay

The most effective wind speeds are: **2-3 m/s with %12, 6-7 m/s with %12 and 7-8 m/s with %14.**

Therefore, according to the power curves of wind turbines (SWT2.3-82 / SWT2.3-93 / SWT2.3-101 / SWT3.6-120 / SWT6.0-154), the average energy production in different wind speed ranges has been calculated. And this calculation is combined with the distribution of the wind speed ranges determined above.

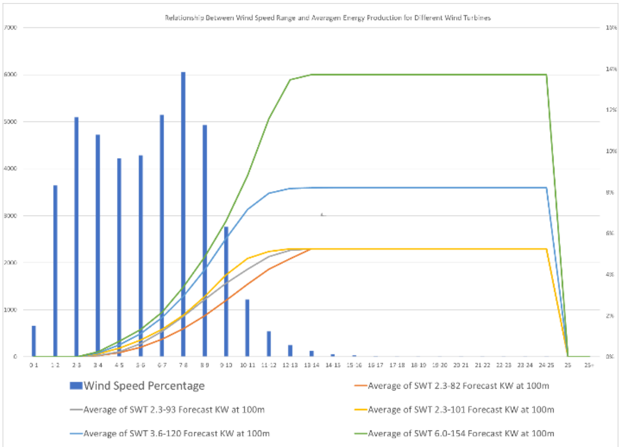

Figure 34 Wind Speed Range and Relationship with SWT Models Power Curves

Since SWT6.0-154 and SWT3.6-120 are effective in the wind speed range of 9 m/s and above, elimination needs to be done on different rotor diameters of SWT2.3 type.

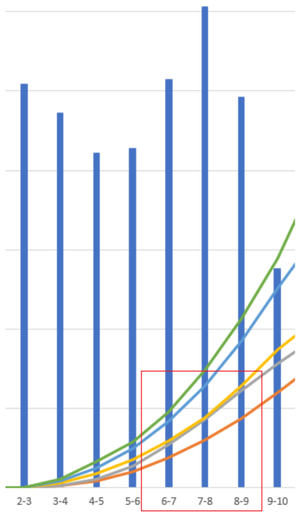

Figure 35 Wind Speed Range and Relationship with SWT Models Power Curves

As can be seen in the square marked in the graph above, in the range where the wind speed is most effective, the energy production of SWT2.3-82 is low, while SWT2.3-93 and SWT2.3-101 are almost the same.

So, considering COE and AEP relationship, **SWT2.3-93** would be the best choice for wind farm in Bangui Bay.

As additional information, the annual total energy produced according to the distribution of hourly wind speed ranges between 1985 and 2021 are given below.

Wind Speed Ranges	Hours of Wind Speeds Ranges Measured	Wind Speed Rages Percentage	Sum of SWT 2.3-82 Forecast KWh at 100m	Sum of SWT 2.3-93 Forecast KWh at 100m	Sum of SWT 2.3-101 Forecast KWh at 100m	Sum of SWT 3.6-120 Forecast KWh at 100m	Sum of SWT 6.0-154 Forecast KWh at 100m
0-1	4834	1,49%	0	0	0	0	0
1-2	27015	8,33%	0	0	0	0	0
2-3	37735	11,63%	0	0	0	0	0
3-4	34990	10,79%	821980,43	1026599,70	2185023,09	2871804,94	3849321,32
4-5	31243	9,63%	2758199,52	3337916,46	5724097,24	7973016,24	10256886,49
5-6	31716	9,78%	6514000,67	8815068,66	11385183,65	15632639,52	18392705,93
6-7	38108	11,75%	14312295,09	20648648,82	22411419,71	31875774,43	36337266,53
7-8	44882	13,84%	26934794,93	38713331,86	39930522,78	57809464,89	66791122,29
8-9	36504	11,25%	31855253,28	44507148,95	46898652,52	67463589,17	77695906,15
9-10	20468	6,31%	24507716,53	31976022,63	35691137,50	51471709,05	59104827,30
10-11	9031	2,78%	13958825,50	16857273,22	18912992,71	28282196,78	34819340,71
11-12	4014	1,24%	7470487,44	8548119,01	9004693,32	13964279,51	20331216,52
12-13	1803	0,56%	3766026,93	4089672,14	4148509,19	6457155,59	10628082,56
13-14	898	0,28%	2065400,00	2065400,00	2065400,00	3229208,00	5388000,00
14-15	411	0,13%	945300,00	945300,00	945300,00	1479600,00	2466000,00
15-16	191	0,06%	439300,00	439300,00	439300,00	687600,00	1146000,00
16-17	125	0,04%	287500,00	287500,00	287500,00	450000,00	750000,00
17-18	81	0,02%	186300,00	186300,00	186300,00	291600,00	486000,00
18-19	60	0,02%	138000,00	138000,00	138000,00	216000,00	360000,00
19-20	55	0,02%	126500,00	126500,00	126500,00	198000,00	330000,00
20-21	26	0,01%	59800,00	59800,00	59800,00	93600,00	156000,00
21-22	23	0,01%	52900,00	52900,00	52900,00	82800,00	138000,00
22-23	18	0,01%	41400,00	41400,00	41400,00	64800,00	108000,00
23-24	14	0,00%	32200,00	32200,00	32200,00	50400,00	84000,00
24-25	14	0,00%	32200,00	32200,00	32200,00	50400,00	84000,00
25	13	0,00%	0	0	0	0	0
25+	64	0,02%	0	0	0	0	0
Grand Total	**324336**	**100%**	**137306380,3**	**182926601,4**	**200699031,7**	**290695638,1**	**349702675,8**

Figure 36 Annual Energy Production for Different SWT Models

10.9Wind Turbine Hub Height Selection

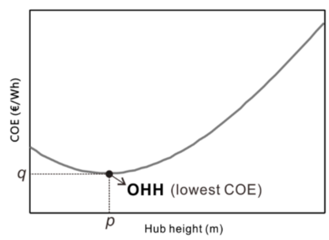

Figure 37 Cost of Energy Curve Relationship with Hub Height

So, for finding optimum hub height, calculated Estimated Annual Energy Production at 80m, 90m and 100m hub height for SWT2.3-93 Wind Turbine.

Years	Estimated Annual Energy Production (kWh) at 80M Hub	Estimated Annual Energy Production (kWh) at 90M Hub	Estimated Annual Energy Production (kWh) at 100M Hub
1985	4702246,62	4812084,20	4910426,42
1986	4912310,38	5026049,83	5127840,79
1987	4257923,59	4355315,41	4440252,15
1988	4908857,61	5016333,60	5112389,06
1989	5434924,75	5551331,10	5655514,93
1990	4685731,92	4794451,81	4891818,98
1991	4854997,29	4962295,25	5062428,77
1992	4195565,88	4293330,69	4380865,26
1993	4891778,04	4996136,86	5089540,01
1994	4702751,19	4811462,12	4908798,64
1995	4917078,92	5028997,36	5129120,97
1996	5665142,40	5787267,34	5896450,58
1997	4275334,40	4377985,90	4469982,20
1998	4094344,66	4183773,88	4263691,43
1999	4911957,80	5023108,85	5122620,03
2000	5077340,92	5191724,58	5294073,29
2001	4958104,59	5070804,52	5171696,64
2002	4650747,41	4759432,74	4856620,27
2003	4905630,79	5020387,13	5123138,09
2004	4807177,77	4922794,66	5026406,99
2005	4613486,82	4719990,63	4815358,27
2006	4637827,62	4748256,88	4847102,04
2007	4673520,21	4785335,20	4885475,50
2008	5335012,48	5452823,02	5558165,99
2009	4816191,27	4924716,61	5021832,59
2010	3668090,83	3755814,10	3836473,07
2011	5606457,15	5724055,75	5829224,35
2012	4553011,17	4659743,27	4755291,03
2013	4830897,60	4944387,78	5045964,88
2014	4570119,66	4677475,41	4773529,60
2015	4504455,33	4603914,59	4690373,38
2016	3800398,54	3891036,58	3972210,13
2017	4889967,33	4999583,46	5097677,52
2018	4597062,32	4706474,95	4802223,19
2019	4150331,81	4249863,10	4338968,25
2020	4844535,06	4954648,64	5053193,38
2021	5306166,31	5431240,02	5543273,83
Grand Total	**175207478,4**	**179214427,8**	**182800012,5**
Grand Average	**4735337,255**	**4843633,184**	**4940540,879**

Figure 38 Average Energy Production at Different Hub Height for SWT2.3-93 Model

Because Hub cost is unknown, no comparison made between COE and OHH. Since only the average price difference between the hub heights is known, a simple proportion was made, and an additional **383.900-euro** investment was deemed appropriate for an additional **205.203 kWh** annual production per year.

Hub Heights	Apprx Hub Cost	Estimated Annual Energy Production	
80m	x	y	4735337,25 kWh
90m	x+160.000 €	y+108.295 kWh	4843633,18 kWh
100m	x+383.900 €	y+205.203 kWh	4940540,87 kWh

Figure 39 Cost Estimation According to Hub Height

Hereby, hub height has been chosen **100m.**

10.10 Sketch And Layout Plan of Bangui Bay Project

10.10.1 Sketch

A common rule of micro-sitting of wind turbines is three to five rotor diameters in cross wind directions. Even less than three is possible under some circumstances.

So micro-sitting is showed below with three rotor diameters, layer unit is decameter (dam).

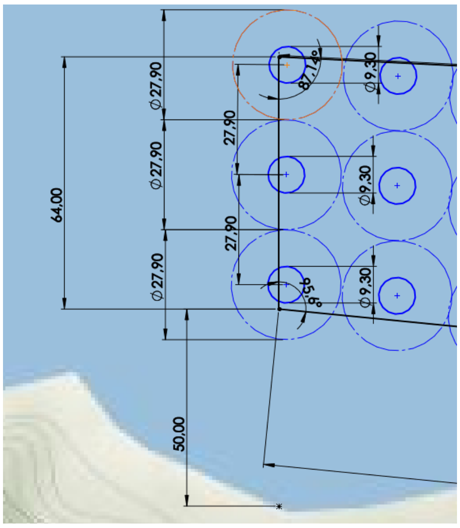

Figure 40 Micro-sitting of Wind Turbines

Thus, **103** wind turbines can fit to area which has determined from water depth map.

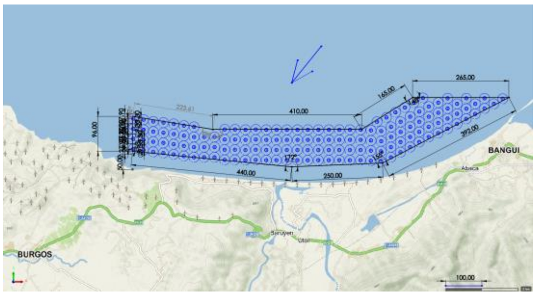

Figure 41 Wind Turbine Installation Area (Micro-sitting of 103 Pieces)

10.10.2 Layout

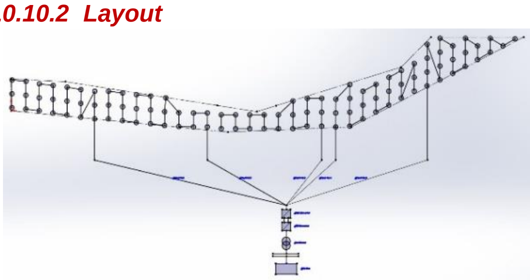

Figure 42 Grid Connections in Selected Area

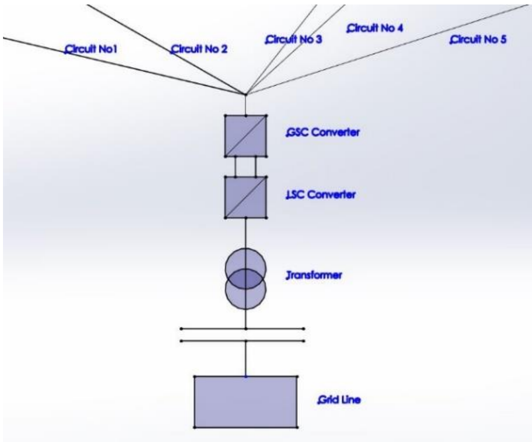

Figure 43 Grid Connection Layout Detail

There will be five circuit between wind turbines and the grid line for **103 wind turbines**. Estimated length of submerged cable will be **58.000m** for all connections, including wind turbines each other.

10.11 Capacity Of Wind Farm

Years	Sum of SWT 2.3-93 Forecast KWh at 100m	Sum of SWT 2.3-82 Forecast KWh at 100m	Sum of SWT 2.3-101 Forecast KWh at 100m	Sum of SWT 3.6-120 Forecast KWh at 100m	Sum of SWT 6.0-154 Forecast KWh at 100m
1985	4913748,49	3676193,98	5372744,16	7779341,01	9412713,49
1986	5131300,54	3838207,87	5632716,77	8148182,57	9753009,78
1987	4443788,70	3354226,19	4892908,97	7087815,87	8589015,57
1988	5116004,09	3879862,04	5600891,62	8141072,97	9883323,50
1989	5658939,08	4313931,84	6179473,41	8982979,46	10973240,64
1990	4895175,22	3654791,35	5346022,25	7740034,78	9300868,59
1991	5066103,46	3800015,22	5543012,84	8033479,90	9713783,88
1992	4384686,84	3302152,07	4833291,13	7000057,05	8496745,56
1993	5093430,34	3908149,85	5544149,91	8092058,61	10031295,68
1994	4912064,48	3690532,58	5386708,11	7809217,76	9442778,18
1995	5132071,77	3867568,76	5627289,54	8159068,61	9888979,40
1996	5899721,76	4468176,92	6447518,87	9371201,99	11304977,42
1997	4473859,49	3328722,53	4926572,26	7112567,43	8515494,25
1998	4268490,23	3270275,81	4683229,58	6806429,89	8426390,29
1999	5125847,00	3843551,98	5648067,39	8175401,54	9734980,11
2000	5297667,56	3989452,71	5799896,81	8404246,98	10134256,06
2001	5175038,17	3877971,54	5689314,42	8235891,45	9822066,11
2002	4860059,54	3632637,06	5337766,88	7723308,09	9285054,94
2003	5126552,05	3829151,22	5638960,19	8156529,74	9730643,97
2004	5029208,62	3728717,11	5502503,77	7946276,84	9459114,01
2005	4818852,21	3608454,23	5289579,98	7662184,64	9186082,46
2006	4850144,13	3624597,68	5371696,75	7761099,83	9259875,48
2007	4888966,91	3604509,68	5351584,53	7723551,48	9107471,18
2008	5561300,21	4185626,23	6076081,68	8819355,90	10581394,59
2009	5025148,34	3782931,97	5499074,17	7981649,42	9621948,27
2010	3840351,10	2836019,22	4246552,04	6111750,72	7224844,20
2011	5832185,34	4464319,96	6398430,18	9313895,59	11305279,57
2012	4758875,28	3554534,41	5255498,33	7591409,78	9045464,63
2013	5049145,21	3752971,90	5523631,45	7978844,43	9526015,92
2014	4776970,48	3563918,83	5252039,97	7590978,45	9066832,47
2015	4693684,49	3551042,28	5139991,29	7463246,27	9078262,83
2016	3975857,21	2968514,78	4392892,48	6349627,63	7613645,25
2017	5100927,37	3836066,81	5606208,15	8123358,19	9759243,65
2018	4805672,46	3590997,29	5283677,72	7639804,07	9199547,33
2019	4342484,41	3222340,53	4753663,71	6866327,30	8217187,28
2020	5056474,10	3794361,90	5551189,25	8038852,79	9621476,17
2021	5545804,79	4110884,00	6074201,14	8774539,04	10389373,07
Grand Total	182926601,4	137306380,3	200699031,7	290695638,1	349702675,8
Grand Yearly Average of AEP	4943962,20	3710983,25	5424298,15	7856638,87	9451423,67

Figure 44 Average and Annual Energy Production for All SWT Models

First of all, when examining the wind farm capacity, the values of wind speeds measured hourly between 1985-2021, 100m Height Wind Speed values were calculated with the Weibull distribution (**324.336 wind speed data by hourly**)

Then, according to the power curves of wind turbines, the power to be produced depending on the wind speed was calculated with the excel forecast.ets approach.

CP = AEP / Wind Turbine Capacity x 8760 hour
But for AEP Calculations, Out of Cut-in or Cut-out times weren't calculated therefore average of yearly hours calculated. (Between 3-25 m/s)

Years	Out Of Cut-in or Cot-out Hours	Working Hours	Grand Total
1985	1675	7085	8760
1986	1681	7079	8760
1987	2267	6493	8760
1988	2162	6622	8784
1989	1638	7122	8760
1990	2005	6755	8760
1991	1580	7180	8760
1992	2080	6704	8784
1993	2058	6702	8760
1994	1813	6947	8760
1995	1693	7067	8760
1996	1729	7055	8784
1997	1936	6824	8760
1998	2326	6434	8760
1999	1999	6761	8760
2000	1699	7085	8784
2001	1905	6855	8760
2002	1851	6909	8760
2003	1611	7149	8760
2004	1634	7150	8784
2005	2094	6666	8760
2006	1626	7134	8760
2007	2088	6672	8760
2008	2010	6774	8784
2009	2126	6634	8760
2010	2678	6082	8760
2011	1857	6903	8760
2012	1991	6793	8784
2013	1792	6968	8760
2014	1941	6819	8760
2015	2162	6598	8760
2016	2562	6222	8784
2017	2060	6700	8760
2018	1518	7242	8760
2019	2365	6395	8760
2020	2069	6715	8784
2021	1465	7295	8760
Grand Total	71746	252590	324336
Grand Average	**1939**	**6827**	**-**

Figure 45 Approximate Cut-out or Out-of-Cut-in Hours by Year

Thus:

CP = AEP / Wind Turbine Capacity x 6827 h

CP = 4.943.962,2 /15.701.540,5

CP = 0,314 (Which should be between 0,25-0,35 for offshore)

Wind farm capacity:

Number of Wind Turbines x AEP of 1 Wind Turbines

103 x 4.943.962,2 kWh = 509.228.106,6 kWh/Year

10.12 Required Inventory List of Bangui Bay Project

Requirment	Pieces
Tower/Hub	103
Nacelle Assembly	103
Rotor	103
Blades	309
Substation Units	103
Gridline Connection Converters	103
Jackup Barge	1
Jackup Vessel	1
Open Deck Cargo Ship	2
Cable Layer Vessel	1
Tender Wessel	2
Zodiac	2
Accomandation Vessel (20 people)	2

Figure 46 Inventory List for Wind turbines in Installation Area

10.13 Installation of Bangui Bay Project

10.13.1 Logistic of Bangui Bay Project

Wind turbines consist of approximately 8 thousand parts. The selected wind turbine is in the range of approximately **315-350 tons**. All wind components are shipped by using trucks, wagons and ships. Transportation processes are the turbine transportation, suitable port selection, route study, selection of appropriate vehicles, obtaining the necessary permits/measures, ship unloading, stocking and transportation at the port.

Since the installed wind turbines will be built in the open seas, logistic is important thing from factory to work site. The first thing to do here is to find the shortest distance from the place of production to the place where it will be established. Unfortunately, there is no production factory of wind turbines in the Philippine region. For this reason, the existing production sites of the model that was decided were investigated.

Unit	Brand	Production Place	Weights
ROTOR	Siemens Gamesa	Tianjin (China)	60 tons
NACELLE EXCL. ROTOR	Siemens Gamesa	Tianjin (China)	82 tons
TOWER (100m)	Siemens Gamesa - Welcon	Tianjin (China)	182 tons
BLADES	Siemens Gamesa	Linggang (China)	11 tons

Figure 47 Approximate Weights of Wind Turbine Parts

The shipping process will consist of 2 phases. First phase is from the production place to major port of Philippines. The nearest major port to Bangui Bay is Manila Port.

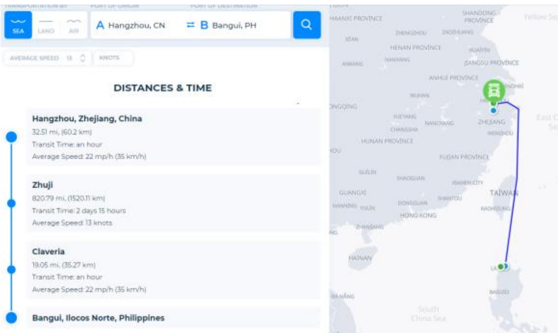

Figure 48 Closest Way from China to Philippines (Manila Port)

1.Phase:

Equipments	ROTOR	NACELLE EXCL. ROTOR	TOWER (80m)	BLADES	OTHERS
Aprox. Dimensionless	3m diameter	6m*2m*2m	80m -56ϕ	45 m	
Unit Weights	60 ton	82 ton	162 ton	11 ton	35 ton
Pieces	103 pcs	103 pcs	103 pcs	309 pcs	103 pcs
Total Weights	6180 ton	8446 ton	16686 ton	3399 ton	3605 ton
Brand	Siemens Gamesa	Siemens Gamesa	Welcon	Siemens Gamesa	Siemens Gamesa
1.Departure Port	Hangzhou,Zhejiang , China	Hangzhou,Zhejiang , China	Hangzhou,Zhejiang , China	Hangzhou,Zhejiang , China	Hangzhou,Zhejiang , China
1.Arrival Port	Manila Port	Manila Port	Manila Port	Manila Port	Manila Port
Units Carried Per Trip	25	20	10	154	38
Number Of Trip	4	5	10,3	2	9
Period of Trip	15 Day	15 Day	15 Day	15 Day	15 Day
Transit Time	2 Day 17 hours	2 Day 17 hours	2 Day 17 hours	2 Day 17 hours	2 Day 17 hours
Free Time	15 Days	15 Days	15 Days	15 Days	15 Days
Arrival Point	Manila Port WareHouse	Manila Port WareHouse	Manila Port WareHouse	Manila Port WareHouse	Manila Port WareHouse

Figure 49 First Phase of Logistic

According to contract with Siemens Gamesa, delivery term has chosen CIF Manila, Philippines.

Departure port chosen by Siemens Gamesa as Hangzhou, Zhejiang, China.

With an agreement with Philippines Trade Administration / Philippines Port Authority, stockpile area has been allocated at Manila Port for six months.

2.Phase:

Equipments	ROTOR	NACELLE EXCL. ROTOR	TOWER (80m)	BLADES	OTHERS
Aprox. Dimensionless	3m diameter	6m*2m*2m	80m -56ϕ	45 m	-
Weights	60 ton	82 ton	162 ton	11 ton	35 ton
Pieces	103 pcs	103 pcs	103 pcs	309 pcs	103 pcs
Total Weights	6180 ton	8446 ton	16686 ton	3399 ton	3605 ton
Brand	Siemens Gamesa	Siemens Gamesa	Welcon	Siemens Gamesa	Siemens Gamesa
1.Departure Port	Manila Port Ware House	Manila Port Ware House	Manila Port Ware House	Manila Port Ware House	Manila Port Ware House
1.Arrival Port	Bangui Bay	Bangui Bay	Bangui Bay	Bangui Bay	Bangui Bay
Units Carried Per Trip	4	4	4	12	4
Number Of Trip	25	25	25	25	25
Period of Trip	After Every 4 unit installation	After Every 4 unit installation	After Every 4 unit installation	After Every 4 unit installation	After Every 4 unit installation
Transit Time	2 Day 15 Hours	2 Day 15 Hours	2 Day 15 Hours	2 Day 15 Hours	2 Day 15 Hours
Aprox. Construction Time	15 Days	15 Days	15 Days	15 Days	15 Days

Figure 50 Second Phase of Logistic

For transportation to job site and construction, two open deck 100m cargo ship has rented for transportation from Manila to worksite, JU019C Jack up Vessel and JU041C Jack up Barge has rented for construction site works.

2 cargo ships will carry the loads to the jack-ups as 4 sets between the Manila port and Bangui Bay continuously. Capacities and legs lengths of Jack up's given below.

10.13.2 Cranes and Jack up Vessels

For installation, two Jack up Vessel will be rented. Details given below. Other small cranes and equipments will be rented from local suppliers.

Figure 51 Jack up Vessel for Installation Wind Turbines

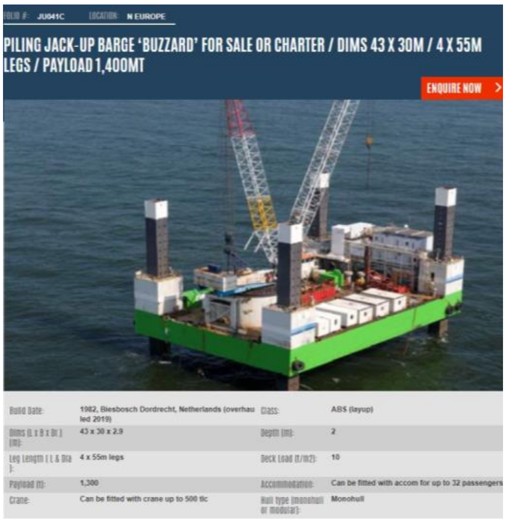

Figure 52 Jack up Barge Vessel for Installation Wind Turbines

10.13.3 Weather Window

	Average Wind Speed (m/s)												Average Temperature
Years	Jan	Feb	Mar	Apr	May	Jun	July	Agu	Sep	Oct	Nov	Dec	
1985	6,02	4,53	5,92	4,36	4,37	2,75	2,64	2,82	3,46	6,13	6,14	6,54	25,58
1986	6,83	5,54	5,15	4,53	3,40	2,97	3,27	3,70	3,85	5,43	5,89	6,11	25,34
1987	6,19	5,83	3,89	3,48	2,28	2,70	2,76	4,01	3,09	4,96	6,18	6,92	26,03
1988	5,48	5,74	4,47	4,48	3,15	2,46	3,74	2,36	2,57	5,75	7,27	7,49	26,18
1989	6,88	6,25	5,70	3,80	3,92	2,85	4,24	3,11	3,72	5,65	6,90	5,88	25,48
1990	6,08	5,17	5,00	3,37	3,25	2,81	2,49	4,37	3,52	5,60	6,08	6,47	25,79
1991	5,77	5,81	5,02	4,45	4,36	4,24	3,08	2,82	3,33	5,20	6,18	6,27	25,68
1992	5,53	4,75	4,12	2,77	3,13	2,45	3,63	3,12	3,68	6,13	6,52	6,55	25,57
1993	6,03	5,95	5,01	4,03	3,27	2,23	2,75	2,64	2,79	5,90	6,72	7,77	25,71
1994	5,86	5,23	6,13	4,09	2,59	2,92	3,27	3,48	3,23	5,51	6,11	6,89	25,57
1995	6,06	5,26	4,87	4,83	3,07	2,48	2,80	2,93	4,37	5,50	6,77	7,58	25,80
1996	6,68	6,67	5,27	5,26	3,16	3,33	3,40	3,10	3,82	4,63	6,49	7,03	25,64
1997	5,85	6,42	5,36	4,10	2,71	2,32	2,88	3,75	3,59	4,58	5,46	6,29	25,63
1998	5,30	4,11	5,13	3,88	3,16	2,63	2,54	2,69	3,18	5,45	5,71	6,91	26,67
1999	6,72	6,75	5,06	5,08	2,89	2,31	2,55	2,96	2,97	5,04	6,52	7,12	25,87
2000	6,39	6,11	5,80	3,72	3,47	2,73	3,35	2,47	4,37	5,86	6,08	6,77	25,96
2001	6,19	6,47	5,03	3,98	2,13	2,71	3,53	2,47	3,99	5,47	7,03	7,11	25,98
2002	5,91	6,17	4,97	5,33	3,93	2,61	3,37	2,92	2,89	4,45	6,23	6,14	26,14
2003	6,48	6,06	5,52	4,42	3,66	3,09	3,59	2,91	3,50	4,96	5,62	7,07	25,76
2004	5,85	5,92	5,09	3,76	4,27	3,98	3,17	3,32	3,42	5,33	6,97	6,40	25,43
2005	5,26	4,93	5,36	4,16	1,93	2,04	3,61	3,23	4,40	5,22	6,39	7,68	25,73
2006	5,64	6,69	4,96	3,58	3,66	3,26	3,81	3,39	3,78	4,98	5,28	7,21	26,11
2007	6,53	5,46	4,93	4,43	2,73	2,67	2,55	3,16	3,05	5,53	6,90	6,69	26,18
2008	6,42	6,80	5,65	4,85	3,03	2,53	3,24	2,57	3,27	4,68	6,73	7,43	25,90
2009	7,03	5,94	4,73	4,48	4,79	2,50	2,31	3,23	3,01	5,36	5,87	5,85	25,79
2010	6,19	3,48	5,13	3,73	2,49	1,83	2,32	2,42	3,64	5,93	6,12	6,14	26,23
2011	7,31	5,61	7,02	5,02	2,86	3,04	2,96	4,11	3,97	4,67	5,73	7,22	25,60
2012	5,86	5,80	6,23	3,19	2,11	2,87	2,82	4,07	4,48	5,49	4,95	6,47	26,10
2013	6,55	6,29	4,51	3,71	2,43	3,08	3,62	4,06	4,10	5,15	6,64	6,19	26,21
2014	6,44	5,12	5,27	4,64	2,33	1,80	3,20	3,83	3,62	5,30	5,74	7,42	25,93
2015	6,66	5,73	5,26	4,57	2,39	1,92	3,24	3,90	3,34	5,42	6,01	5,87	26,03
2016	4,53	5,71	4,49	2,80	2,07	3,07	2,47	3,52	3,18	4,92	6,14	6,99	26,43
2017	6,91	6,33	5,29	3,58	2,52	2,25	3,26	2,76	3,27	5,53	6,18	7,20	26,10
2018	6,28	5,60	5,54	5,07	3,27	2,82	2,78	3,16	3,96	5,30	6,13	6,80	26,11
2019	6,61	5,09	4,37	3,26	2,23	2,10	2,21	4,02	3,76	4,82	6,45	6,66	26,12
2020	6,02	6,42	4,59	4,84	2,49	2,32	2,27	3,28	3,27	6,20	6,91	6,73	26,26
2021	6,75	5,91	5,67	5,55	3,64	3,12	4,03	2,93	3,67	5,39	6,05	6,86	26,03
Grand Total	**6,19**	**5,72**	**5,18**	**4,19**	**3,06**	**2,70**	**3,07**	**3,23**	**3,54**	**5,34**	**6,25**	**6,78**	**25,91**

Figure 53 Weather Window of Bangui Bay

According to Meteoblue History+, Wind Speed and Temperature averages shown above.

In Bangui, which has a tropical climate, the temperature is usually **above 25 degrees**. So, temperature is not problem for installation.

Wave height is related with the wind forecast. So, installations have to schedule in lowest wind speed durations according to crane processes. May-Jun-July and August has lowest wind speed ranges.

10.13.4 Safety / Education

In the installation and maintenance processes of wind turbines, it is necessary to identify and evaluate the risks that may cause work accidents or occupational diseases and to propose solutions for the prevention of these risks.

The most effective course in the implementation of solutions to existing risks is risk assessment that enables the determination and analysis of risks in the working environment.

Working at height: Working conditions are available at an altitude of about 100 meters from the ground. For this reason, working personnel are at risk of falling. As a solution, staff will wear seat belts. Railing systems and safety nets will be used.

Weather conditions: The extreme weather conditions found in offshore wind farms can make operation difficult. Personal protective equipment and equipment will be used for personnel.

Working in a choppy sea: Depending on its location and wind speed, the wave height can reach up to 10 meters. This may pose a danger to working personnel and equipment. The calculated wavelength in the Bangui Bay area is in the range of 2-3 meters. Necessary precautions have been taken.

Safety of Cranes Working in Installation: Cranes for lifting heavy tonnages shall not be operated within 300 cm of any power line. Loads will not be lifted or unloaded from the personnel. Loads shall not be suspended in air for a long time. Personnel assigned for OHS will provide control.

Maintenance of lowering and lifting equipment: Maintenance of all equipment has been done before installation.

Loading and lifting equipment tonnages: It will be mandatory to create load tables for maximum load capacities, working times and conditions. The data will be updated for each new arriving equipment. Work experience period and education status for the operators and masters who will work in the contracts are specified.

Delay of installation approvals: The delay of licenses or approvals for any reason, without any force majeure, has been added to the contracts made.

Education: Wind Farms are usually set up far from living areas. Since they will not be able to reach the hospital quickly in cases of illness/injury, training on first aid will be required for personnel.

10.13.5 Foundation Preparation

Foundations piles and transition tubes are produced by Welcon. And they will transport to site with hub's.

Figure 54 Foundation Preparation (Hub First Pile)

10.13.6 Foundation Installation

The monopile foundation is a simple construction. The foundation consists of a steel pile with a diameter of between 3.5 and 4.5 meters. The pile is driven some 10 to 20 meters into the seabed depending on the type of underground. The mono pile foundation is effectively extending the turbine tower under water and into the seabed.

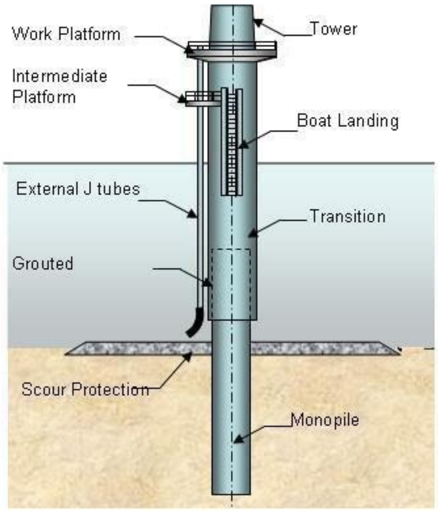

Figure 55 Foundation Installation Example

For foundation installation, "Grippier-Pendulum Design Attachment" is bought from TWD Corporation and attached to rented JU019C.

This attachment is used for piling the first foundation to ground. Also "Hydro Sound Demper" is bought from TWD for making pilling easy.

Figure 56 Jack up Barge Vessel with Grippier-Pendulum Attachment

10.13.7 Turbine Preparation

Blades, rotors, nacelles assemblies are produced by Siemens Gamesa.

Figure 57 Turbine Preparation Example at Siemens Gamesa Factory

10.13.8 Turbine Installation

All components transportation will be done with two open deck 100m cargo ship has rented for transportation from Manila to Bangui Bay, JU019C Jack up Vessel and JU041C Jack up Barge Vessel will be installing the hub, nacelle, rotor and blades by order.

Figure 58 Turbine Installation Example with Jack Up Vessel

10.14 Financial of Bangui Bay Project

Before investing in a country whose conditions are not fully known, the first thing to do is to analyze the country's financial risk reports in order to avoid time and cost losses by gaining experience later.

Figure 59 Philippines Country Report

According to table, economic risk is 3, business environment risk is 4, political risk is 4, commercial risk is 2 and financial risk is 2.

Trade structure by destination/origin
(% of total, annual 2020)

Exports		Rank	Imports	
United States	16.1%	1	22.6%	China
China	15.1%	2	11.2%	United States
Japan	14.4%	3	9.8%	Japan
Hong Kong	14.1%	4	6.5%	Korea, Republic of
Singapore	5.5%	5	6.3%	Indonesia

Figure 60 Import/Export Trade of Philippines (Countries)

Then, it has been researched which products or equipments are mostly imported/exported to which countries.

Trade structure by product
(% of total, annual 2020)

Exports		Rank	Imports	
Electrical machinery, apparatus and appliances, n.e.s.	46.4%	1	21.0%	Electrical machinery, apparatus and appliances, n.e.s.
Office machines and automatic data processing machines	11.3%	2	7.4%	Road vehicles
Vegetables and fruits	4.1%	3	6.7%	Petroleum, petroleum products and related materials
Metalliferous ores and metal scrap	3.0%	4	4.5%	Iron and steel
Telecommunication and sound recording apparatus	2.8%	5	4.1%	Office machines and automatic data processing machines

Figure 61 Import/Export Trade of Philippines (Products)

So, the Philippines carries **medium risk** for an investment.

It is important to determine the expenses and rates of the project for the Finance model and agreements to be created. Installation cost rates of offshore wind turbines are shown in the table below.

Capital Costs	Share %
Wind Turbine	30-50
Grid Connection	15-30
Construction	15-25
Other Capital	8-30

Figure 62 Percentage of Capital Costs

After the cost analysis, it should be analyzed with which companies or partnerships the investment process found suitable should proceed.

Creating Finance Model:

Wind energy finance generally comprises three main sources of capital: equity investor, sponsor and lenders such as banks.

Equity Investors: They often contribute on the condition of operating and partnership agreements.

Lenders: is an individual, a public or private group, or a financial institution that makes funds available to a person or business with the expectation that the funds will be repaid. Repayment will include the payment of any interest or fees.

EPC: Engineering, procurement and Construction Agreements.

PPA: Power Purchase Agreements.

REC: Renewable Energy Agreements.

O&M: Operation and Maintenance Agreements.

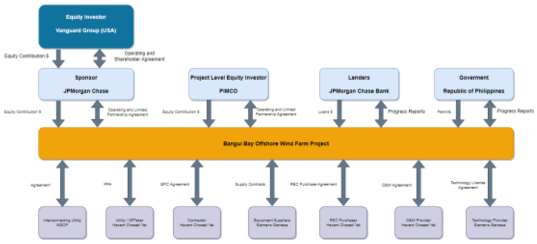

Figure 63 Financial Model and Agreements

Equity Investor: Vanguard Group (USA)

Sponsor: JPMorgan Chase (USA)

Project Level Equity Investor: PIMCO (USA)

Lender: JPMorgan Chase Bank (USA)

American investors were selected, and partnerships were established to benefit from the "USAID INVEST" project.

Government: Republic of Philippines

To take advantage of the Republic Action Project 9513 privileges, an agreement signed with government. These privileges will be;

- Republic of Philippines will set "Feed-In Tariff System" with NGCP (National Grid Corporation of Philippines) for privileges of Grid Connection.
- Republic of Philippines will set an "Commercial and Custom Privileges Agreement" via PPA (Philippines Port Authority. This Agreement includes stockpile area has been allocated at Manila Port for six months.
- Republic of Philippines will set an "Tax Equity Agreement via DTI (Department of Trade and Industry)
- Republic of Philippines will set an "Labor and Employment Privileges Agreement" via DLE (Department of Labor and Employment) for privileges about foreign and local worker.
- Republic of Philippines will set an "Maritime Security Agreement" via PCG (Philippines Coast Guard) Service for protection of Project Areas.

Interconnecting Utility: NGCP (National Grid Corporation of Philippines)

Utility/Off taker: Negotiations still continue.

Contractor: Negotiations still continue.

Equipment Supplier: Siemens Gamesa

REC Purchaser: Negotiations still continue.

O&M Provider: Negotiations still continue.

Technology Provider: Siemens Gamesa

11. Conclusion

Scientific studies and articles related to offshore wind turbines in the Philippines were examined. The country's average wind capacity and annual energy production have been calculated. Possible regions were eliminated depending on their external and internal parameters. Thus, it is decided that the most suitable region is Bangui Bay.

According to Meteoblue History+ Data, Bangui Bay's 1985-2021 wind speed data were examined, and SWT2.3-93 was determined as the most efficient wind turbine model in the region. An estimated sketch was created according to the depth parameter of the region and 103 pieces wind turbines will be installed. Depending on the depth and soil condition parameters, the most widely used Monopile foundation type was chosen.

Capacity of wind farm: 103 pieces x 4.943.962,2 kWh = 509.228.106.6 kWh (Yearly estimated).

Grid connections, which cost around 30% in the installation planning, were examined. It is planned to connect to the nearest (approximately 1 km from the Area) North Luzon Grid line (Laoag City- Bangui Transmission Line). Thus, an extra grid investment will not be required.

According to the country assessment report, the Philippine region has medium risk. The financial model of the project was created according to the financial structure of the country, the privileges offered, investment, risk parities and possible agreements were studied. With the agreements, "Bangui Bay 103 Offshore Wind Turbine project" plan have been secured.

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