Pre Feasibility Study
IPP Offshore Wind Power Plant 10-1000 MW
at Indonesia

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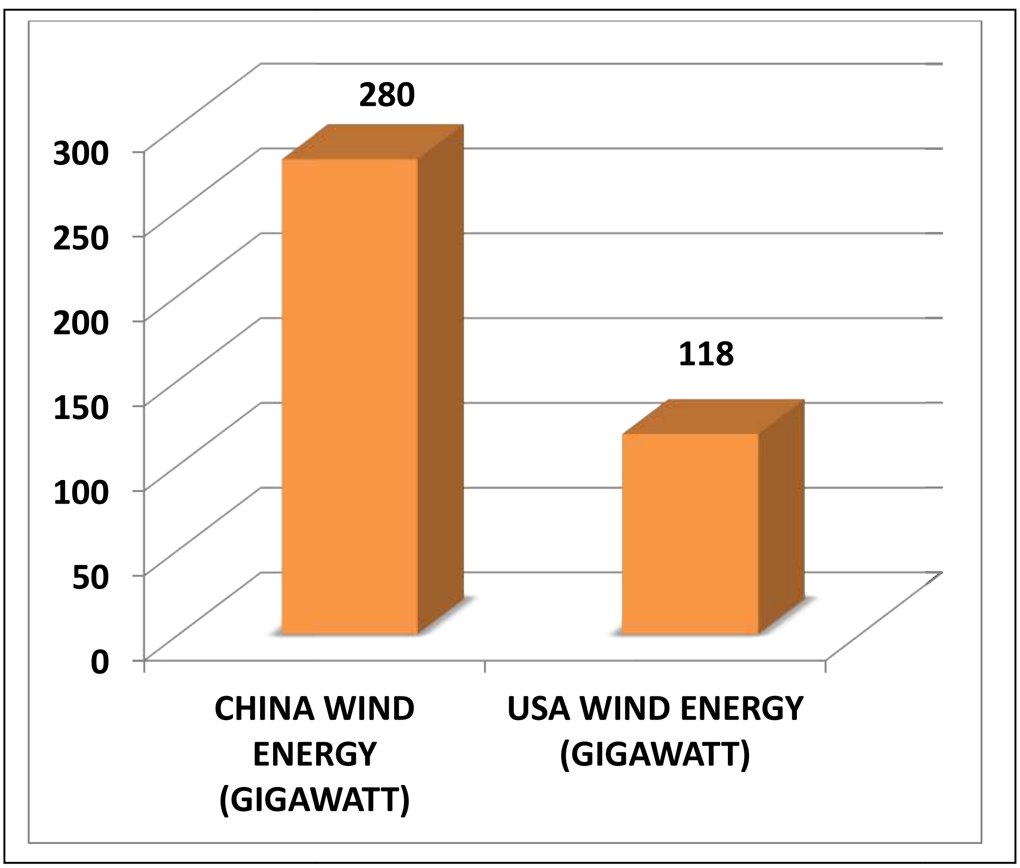
Chapter 1. Introduction

1.1. Project Background

PT Bayu Matahari Indonesia is a newly established company with a deed of approval from the Indonesian Minister of Law No. AHU-0009725.AH.01.01.2021. This company is specifically engaged in the renewable energy power generation industry for solar power and wind power. To provide answers about the latest opportunities of offshore wind turbine technology, we take the initiative to provide information data related to the latest development of offshore wind turbines. If Indonesia in 2021, the installed capacity of wind turbine is 150 MW, of course in the near future, we expect the installed capacity to be above the gigawatt size.

Wind energy as a one of renewable energy is clean and free for all, however, its kinetic potential energy should change to fulfll the need energy consumption by using Wind Energy Conversion System (WECS) to generate electricity or other mechanical energy such for pumping system. To realize these, many activity related to wind energy should be done as wind data resources assessment, research and development (R and D) on wind turbine technology and also introducing and disseminating of using wind energy at several site selection with good enough wind velocity.



The world total wind power generation is about 733 GW. Based on the Global Wind Energy Association (GWEA), China has the biggest wind power generation market in the world with the total of 280 GW or equal with 38% from the total world market. In the second place, is USA with the total wind power generation installed capacity of 118 GW, which took the share of the world total wind energy market about 16%. And in the third place is German with the total capacity of wind power generation installed is 62 GW or equal with 8 % of the world wind energy market.

In the South East Asia, Philippine had developed the wind power generation since 2009; with present total capacity installed is 443 MW. While in Thailand, the total capacity installed of wind power generation is 1.5 GW this year. Vietnam the total capacity installed of wind power generation is 600 MW this year and Indonesia the total capacity installed of wind power generation is 154 MW. In Vietnam, the application of on-grid wind-power generation is targeted to reach 1GW by 2020 and 6.2 GW by 2030. Studies have estimated that Vietnam has good wind energy potency. The study conducted by the World Bank showed that Vietnam's wind energy potency is about 521GW. While the study conducted by the Electricity of Vietnam Group/EVN stated that Vietnam has the potency of wind energy about 1,785GW.

The implementation of wind energy technology in Indonesia is still low. In 2021, the total wind power generation installed in Indonesia is 150 MW of a commercial scale. Several implementation of isolated wind energy systems typically in remote area/location or islands, and they are frequently installed as part of development or research project. Several area along the shore of northern and southern part of Java Island, eastern part of Madura island, southern and northern part of Sulawesi Island, and some part of Nusa Tenggara islands, have applied wind turbine for generating.

One of the most important issue in developing wind energy is the measurement. An exact measurement methode had to be conducted in order to have a valid data on wind energy, especially for the wind speed. This is a very crucial for the technology selection that will be used to generate the electricity. The measurement of wind energy in Indonesia had been conducted more than 15 years ago. Most of it was conducted by the National Institute of Aeronautics and Space (LAPAN). Others are conducted by the National Meteorological Agency (BMG), and consultant from Winrock International - USA, Wind Guard – Germany (in collaboration with local government), Soluziona (in collaboration with MEMR), NipSA_Spain and other relevant institution at several areas in Indonesia.

Based on the data collected, about 166 sites in Indonesia had been measured for the wind energy potency. And the result showed that 35 sites have good potential wind energy, with the average of annual wind speed is above 6 m/s. In addition, about 34 sites also have sufficient wind energy to be developed; with the average of annual wind speed is ranging between 4 – 5 m/sec.

Indonesia has a large archipelago, which consist of more than 17,000 islands and around 5,700 islands only inhabited. Mostly the characteristics of small island is limited for freshwater and electricity supply. The installation cost for freshwater and electricity connection are relatively high. Moreover, there are also barriers in the operation and maintenance activities. The fossil fuel, especially petroleum, will become the simpler solution to electrify the area. However, taking into account the limited availability of the fossil fuel, and also the government programme in reducing green house gases emmision, it is time for us to search and develop the New Renewable Energy (NRE) that available locally in the location.

For remote places, a hybrid system power generation can be implemented by combining two or more NRE sources as power generation. Wind energy is very much fluctuates. In some season the wind can blow very hard while in the other it can barely blowing. To overcome this fuctuating characteristic of wind energy, a hybrid system can be applied, especially for the off-grid application.

Wind power generation can be combined with other power generation such as solar module (PV) or even diesel engine. The main function of generating sets is to take over the supply of electricity during the low of wind speed. The hybrid systems can complementary increase the reliability of the system to work continuously.

1.2. Wind Resources Assessment

The studies are based 2 data of Wind Resources Assessment :

- WhyPGen Data – 23 potential locations of wind power of Indonesia
- Global Wind Atlas

1.2.1. WhyPGen data.

Firstly, WHyPGen mission to encourage implementaion of wind energy in Indonesia. WHyPGen-BPPT has completed WRA on 23 potential locations and pre-FS on 10 location in Indonesia. This map will show the wind speed, wind direction and the potential power density at speci.c locations. This map could be use as the basis to identi.ed and develop the potential WPG in the area.

Indonesia has several location that potential to generate wind power generation (WPG). From Aceh, Southern part of Java, East Nusa Tenggara, South and North Sulawesi, Islands of Eastern part of Indonesia until Papua at certain area have a potential to implementation of wind power generation. Ranging from the large-scale connected to the existing grid to small-scale coastal and isolated islands, this potential must be recorded, measured, mapped and developed. To obtain complete data about it, it is necessary to do Wind Resources Assessment (WRA) to estimate the future energy production of a WPG at certain area. The results of WRA are needed to develop a more complete wind farm Feasibility Study (FS).

Wind Resources Assessment (WRA) is performed in order to predict the wind energy potency in a region. It requires the wind climate secondary data for meso-scale and primary data for the micro-scale. WHyPGen project had conducted WRA in 11 sites, using both data from the satellite and feld visit survey. The WRA are located in 7 provinces, and the total area assessed is around 9,936.53 km2 area. By using a 55 m diameter of wind turbine (or about 750 kW capacity), the simulation resulted that the wind energy in these locations can generate electricity about 2.745 GW or about 55.184 GWh/year.

The data satellite from 3TIER shows that wind energy resources are available in the south coast of Java Island, eastern part of Indonesia (NTT, Maluku) and south part of Sulawesi Island. Nevertheless, some part of Sumatera, Kalimantan and Papua, especially the islands, also had resources for wind energy which can be utilized to generate electricity.

From the assessments, some locations had been identifed to have a good potency to be developed as a commercial grid-connected wind farm. The site selection and capacity generated will not only depend on the average wind speed, but also the area wide.

The process of preparation of Wind Resources Assessment (WRA), the use of WAsP (Wind Analysis Application Program), with supporting several software such as : Global Mapper, Surfer and Map Editor. In this work, the following state of the art freely available sources of data have been used, input data for WAsP :

- ✓ Wind data, in situ the measurement mast, with minimum 1 year period.
- ✓ Others wind data from Mesoscale time series, speed and direction (re-analysis of data from 3TIER downscaling).
- ✓ Terrain that the data used was taken from the Digital Elevation Model (DEM) - Satellite or spacecraft of Shuttle Radar Topographic Mission (SRTM), 90m resolution.
- ✓ Roughness length is taken from National Institue of Aeronautics and Space (LAPAN) at Data and Remote Sensing Center, is overlaid into vector maps by using Map Editor software.
- ✓ The area of analysis which is 20 km (magnitude of the point of reference sites).

1.2.2. Global Wind Atlas

Secondly, the Global Wind Atlas is a free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world, and then perform preliminary calculations. The Global Wind Atlas facilitates online queries and provides freely downloadable datasets based on the latest input data and modeling methodologies. Users can additionally download high-resolution maps of the wind resource potential, for use in GIS tools, at the global, country, and first-administrative unit (State/Province/Etc.).

The current version of the Global Wind Atlas (GWA 3.1) is the product of a partnership between the Department of Wind Energy at the Technical University of Denmark (DTU Wind Energy) and the World Bank Group (consisting of The World Bank and the International Finance Corporation, or IFC). Work on GWA 2.0 and GWA 3.0 was primarily funded by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank and supported by 13 official bilateral donors. It is part of the global ESMAP initiative on Renewable Energy Resource Mapping that includes biomass, small hydropower, solar energy, and wind energy. GWA 3.0 builds on an ongoing commitment from DTU Wind Energy to disseminate data and science on wind resources to the international community.

GWA 3.0 represents a major upgrade from GWA 2.0 and the first version of the Global Wind Atlas (GWA 1.0). GWA 1.0 was developed by DTU Wind Energy under the framework of the

Clean Energy Ministerial (CEM) and, in particular, the CEM Working Group on Solar and Wind Technologies, led by Germany, Spain and Denmark. GWA 1.0 combined the WAsP microscale model with reanalysis data to provide the first freely available high resolution global map of the wind resource. GWA 1.0 was funded by the Technology Development and Demonstration Program of the Danish Energy Agency (EUDP 11-II, 64011-0347) as the Danish contribution to the objectives of the CEM working group. GWA 1.0 was launched in 2015, and benefitted from collaboration with IRENA and the MASDAR institute. These two partners had a significant impact on the development of GWA 1.0 due to their ability to bring various energy stakeholders together.

In GWA 2.0, the focus was on improving the large-scale wind resource data and the website. To provide improved large-scale wind data, the World Bank Group selected Vortex, a leading commercial provider of wind resource data analysis, to carry out a global mesoscale modeling simulation at 9km resolution using the latest, at the time, ERA Interim reanalysis data, to replace the coarser reanalysis data used in GWA 1.0. The microscale modeling in GWA 2.0 was still performed using the DTU Wind Energy WAsP methodology that was used for GWA 1.0, to carry out microscale model calculations at a 250 m grid spacing. In addition to the data improvements, DTU Wind Energy subcontracted Nazka Mapps to reimagine the GWA web-interface providing an improved user experience and enhancing the value to users of the data.

In GWA 3.0, the wind resources have been calculated even more accurately, using the best available methods and input data. This time, Vortex carried out 10 years of mesoscale time-series model simulations rather than ensemble modeling that cover the globe at a 3 km resolution, forced with the latest ERA5 reanalysis data. In addition to improved atmospheric data, GWA 3.0 used improved elevation and landcover data in the microscale modelling. The mesoscale and microscale model simulations were expanded to include locations up to 200 km from all shorelines , to provide additional information on the offshore wind resource. It also included results at two additional heights 10 m and 150 m to reduce the uncertainty when interpolating the results in the vertical.

To better understand the impacts of the improved modeling in GWA 3.0, DTU Wind Energy carried out a validation of the new dataset. This ongoing task uses data from ESMAP-funded measurement campaigns and other high-quality publicly available wind data. At the time of the GWA 3.0 release, validation has been performed using data from ESMAP-funded measurement campaigns, implemented by the World Bank, for Pakistan, Papua New Guinea, Vietnam, and Zambia. Finally, additional features and functionality have been added to the GWA website by DTU Wind Energy and Nazka Mapps, as part of the 3.0 launch The first feature is an energy yield calculator tool, which allows users to create downloadable GIS data for annual energy production, capacity factor, or full load hours using their own custom wind turbine power curve. The second feature allows users to explore the temporal aspect of the wind resource. The variation of the mean wind speed can be found by year, month, and hour. Users can find areas where the wind resource tends to be load-following, i.e. matching the development in hourly or monthly electricity demand. Users can also combine this information with similar temporal data e.g. solar resources available under the Global Solar Atlas, to identify areas where wind and solar complement each other seasonally or during a typical day.

The GWA website will continue to be developed, owned and operated by DTU Wind Energy. Future upgrades and improvements under the partnership with the World Bank Group and ESMAP are already planned.

DTU wishes to thank all organizations and individuals involved in the development of the Global Wind Atlas, including those not listed above, who have provided important input data, review, and feedback. In particular, DTU would like to acknowledge the funding provided by ESMAP for development of GWA 2.0 and GWA 3.0, and advice, review and other non-financial inputs provided by staff and consultants from DTU, World Bank Group (including ESMAP), and Vortex.

The Global Wind Atlas helps policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world

- ✓ Global onshore coverage
- ✓ Offshore coverage up to 200 km from the shoreline
- ✓ Wind resource mapping at 250 m horizontal grid spacing
- ✓ Wind resource mapping at 10, 50, 100, 150 and 200 m above ground/sea level

The Global Wind Atlas helps policymakers and investors perform preliminary calculations

- ✓ Users can assess the wind resource at a point, over a custom area, or within a country or first adminstrative unit (state/province/etc.)
- ✓ Users can assess the variability of wind resource by year, month, and hour

The Global Wind Atlas facilitates online queries and provides downloadable datasets based on the latest input data and modeling methodologies

- ✓ Users can access the latest data, tools, and methodologies
- ✓ Users can download GIS data for all layers at a point, in a custom area, or within a country or first adminstrative unit
- ✓ Users can download WAsP LIB files

The Global Wind Atlas allows users to download high-resolution maps showing global, country, and first adminstrative unit wind resources

- ✓ Mean wind speed and mean wind power density maps for the world and a selection of countries and first adminstrative units can be downloaded as high-resolution maps in PNG and PDF format
- ✓ The map generation tool provides on-the-fly generation of customized maps of capacity factor, mean wind power density, mean wind speed, orography and roughness length, in PDF format
- ✓ The energy yield calculator tool allows users to assess the energy yield of a generic or custom wind turbine by creating downloadable GIS-data for annual energy production, capacity factor, or full load hours

The Global Wind Atlas is validated

- ✓ Validation is an ongoing task that uses data from ESMAP-funded measurement campaigns and other public high-quality wind data
- ✓ Validation has currently been performed using data from ESMAP-funded measurement campaigns implemented by the World Bank in Pakistan, Papua New Guinea, Vietnam, and Zambia

The Global Wind Atlas is free for all users

- ✓ Free access to all the latest data, tools and methodologies
- ✓ Major improvements and upgrades planned to the data and the tools available

The Global Wind Atlas (GWA) primarily supports wind power development during the exploration and preliminary wind resource assessment phases prior to the installation of meteorology measurement stations on site. It also serves as a useful tool for governments to get a better understanding of their wind resource potential at provincial and local levels.
Objectives

The objectives of the GWA are to:

- ✓ provide wind resource data accounting for high-resolution effects;
- ✓ use microscale modeling to capture small-scale wind speed variability (crucial for better estimates of total wind resource);
- ✓ use a unified methodology over the entire globe and update the Global Wind Atlas as methodologies develop;
- ✓ ensure transparency about the methodology used;
- ✓ support the verification of the results in the long-term by coupling to measurement data and campaigns.

The correct usage of the Global Wind Atlas dataset is for aggregation, upscaling analysis and energy integration modeling for energy planners and policy makers. It is not correct to use the data and tools for wind farm siting.
Limitations of the Global Wind Atlas

The GWA uses two major modeling components that can introduce uncertainty into the calculations. These components are the mesoscale modeling and the microscale modeling.

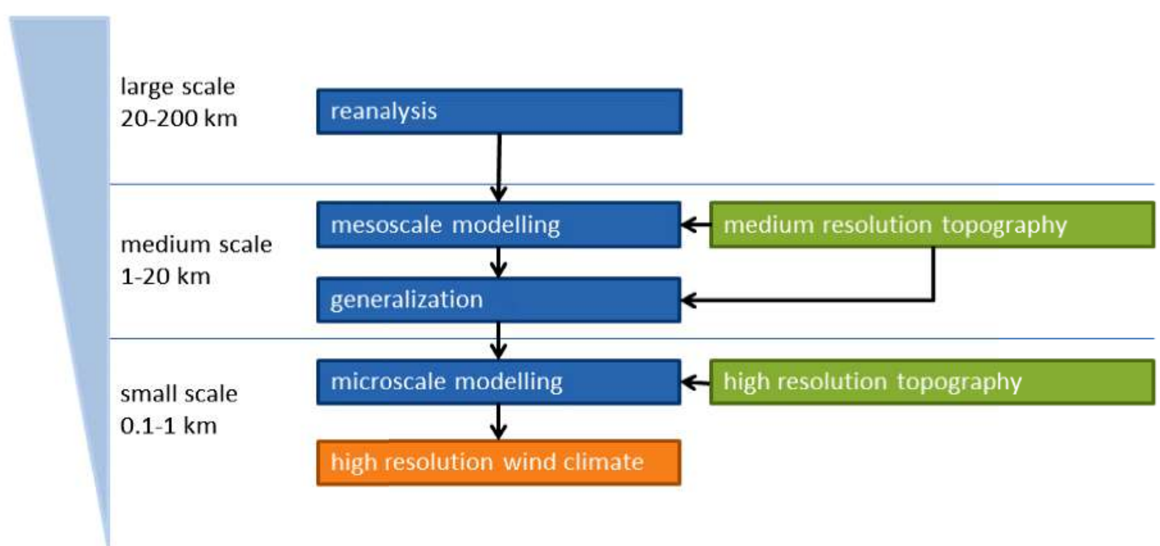
Uncertainties associated with the mesoscale modeling include: representativeness of the large scale forcing and sampling, model grid size, description of the surface characteristics, model spin-up, simulation time and modeling domain size.

Uncertainties associated with the microscale modeling include the orographic flow model within WAsP, the surface description and departures from the reference wind profile. Concerning the orographic flow model, the model performs well when the surrounding terrain is sufficiently gentle and smooth to ensure mostly attached flows. With the global coverage of the GWA, we use the BZ-model in areas beyond its recommended operational envelope.

The GWA website allows users to see where the flow modeling is likely to be increasingly uncertain, by adding a RIX layer to the set of maps. The RIX layer represents ruggedness index and is an objective measure of the steepness or ruggedness of the terrain. Large RIX values will lead to large errors in the flow modeling, most likely leading to an overestimation of mean wind speeds on ridges and hilltops. We therefore recommend users to inspect the RIX of their region of interest.

The GWA uses a downscaling process. We begin with large-scale wind climate data and end with microscale wind climate data. The large-scale wind climate data is provided by atmospheric re-analysis data, in GWA version 3, the ERA5 dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF) is used for the simulation period 2008-2017. The data are located on a grid with a spacing of approximately 30 km. This data is used to force the WRF mesoscale model using a grid spacing of 3 km. We perform a generalization process on this data. The result is a set of generalized wind climates that have the same spacing as the mesoscale data that was used to create them.

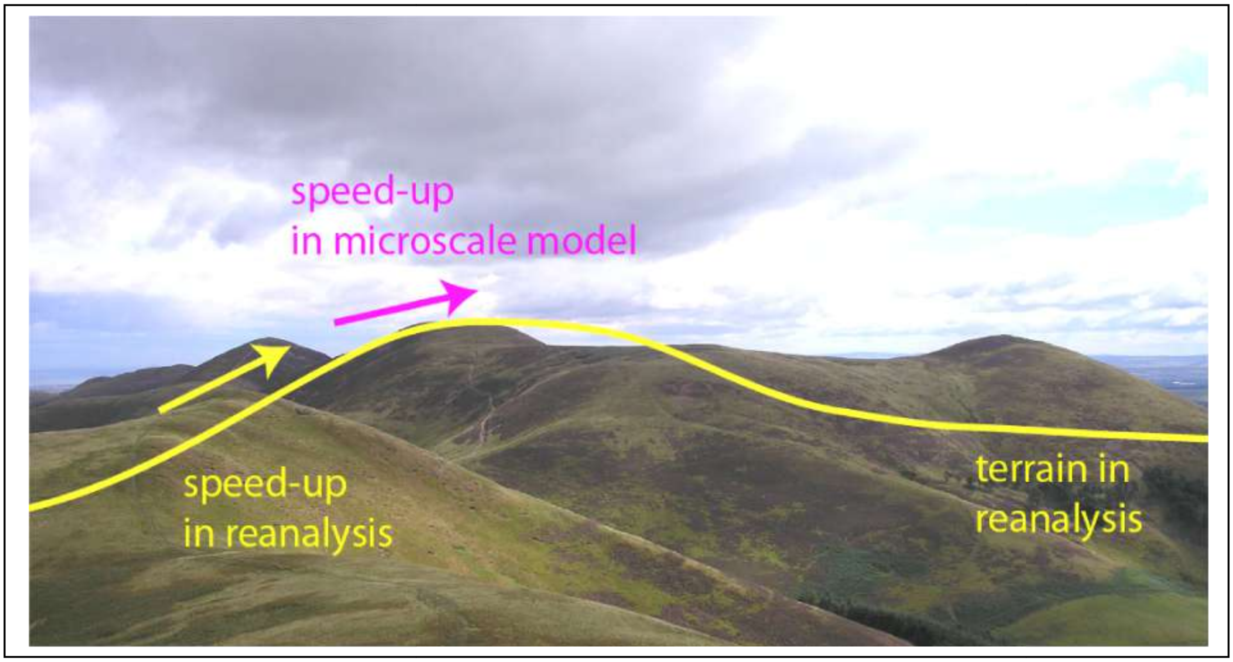
Next, we take this set of generalized wind climates and apply them in our (DTU Wind Energy) microscale modeling system over the globe (except the North and South Poles and far offshore ocean areas). The modeling process is made up of a WAsP calculation of local wind climates for every 250 m at five heights: 10 m; 50 m; 100 m; 150 m and; 200 m. On a 250 m grid, there is a local wind climate estimate for every node. Datasets and tools for analyzing statistics based on the 250 m grid values are available on the GWA website.



Schematic showing the methodology of the GWA is downscaling. Large scale atmospheric data from re-analysis datasets are used as an input into medium scale mesoscale atmospheric models. The output from the mesoscale modeling is generalized to prepare it for use in microscale modeling. The output of the microscale modeling is predicted wind climates, which account for high resolution topography, such as hills, ridges and land use, such as grasslands and forests.

The concept of a generalized wind climate is a key element of the wind atlas methodology developed at DTU Wind Energy. The European Wind Atlas explains the method fully. Since then, the generalization method has been used in numerical wind atlas methodologies, where mesoscale modeling output is generalized before being applied in microscale modeling with WAsP. In this chapter, we describe the generalization fundamentals and how the method used in the mesoscale modeling has been adapted to the re-analysis data.

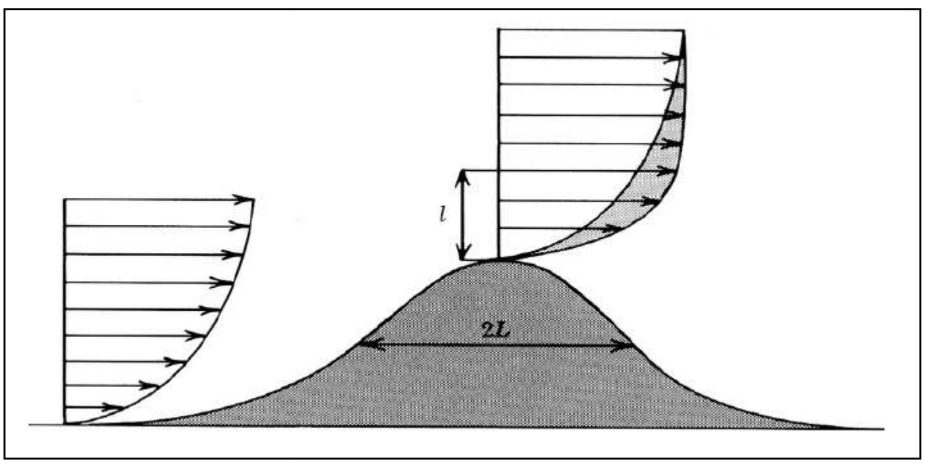
The descriptions of the topography and the land surface in the mesoscale model are, in nature, very distinct. The topography-induced speed-up in reality and in the microscale model are thus quite different from that in the mesoscale model. Furthermore, the coarser mesoscale grid misrepresents details of e.g. the position of the coastline.



Illustrations of how terrain and coastlines are represented in a mesoscale model compared to the terrain and coastlines at higher resolution.

When coupling the mesoscale model results to the microscale model, effects that have a similar scale to what is simulated in the microscale model must be removed from the mesoscale results. Otherwise, we end up double counting. We call this process "generalization" within the WAsP-thinking and wind atlas method developed at DTU Wind Energy. The wind atlas method is based on the generalization of the wind climates that are derived from mesoscale modeling. This generalization post-processing method has been used extensively in a number of wind resource assessment studies, particularly within the KAMM-WAsP method. The method was used for the first time with WRF model simulations in the Wind Atlas for South Africa (WASA) project, which was developed by DTU wind energy.

In this section, the effects of high-resolution terrain and microscale modeling are described. It is in this modeling application that the generalized wind climates provide local wind climates for every 250 m. To run the modeling over the very large area, a system of software and servers called the GWA Frogfoot was developed. This method is very similar to what is used in the WAsP software. For example, the flow modeling for orography, roughness and roughness change is the same in the WAsP software. However, the GWA calculation differs in a number of ways in order to allow a very large area to be covered. For example, local wind climate calculations are based on more than a single generalized wind climate, and terrain data is input as raster maps rather than vector maps.The WAsP software contains flow models for orography, roughness and roughness change effects, and obstacle effects. The GWA does not include obstacle effects. Schematic diagrams illustrate the change of wind flow caused by a hill. The maximum speed-up is at the top of the hill, the magnitude of the speed-up and the height above surface of the maximum speed-up is related to the geometry of the hill. WAsP uses the BZ-model to calculate the orographic speed-up. The flow model uses a high-resolution, zooming, polar grid, centered on the calculation node.

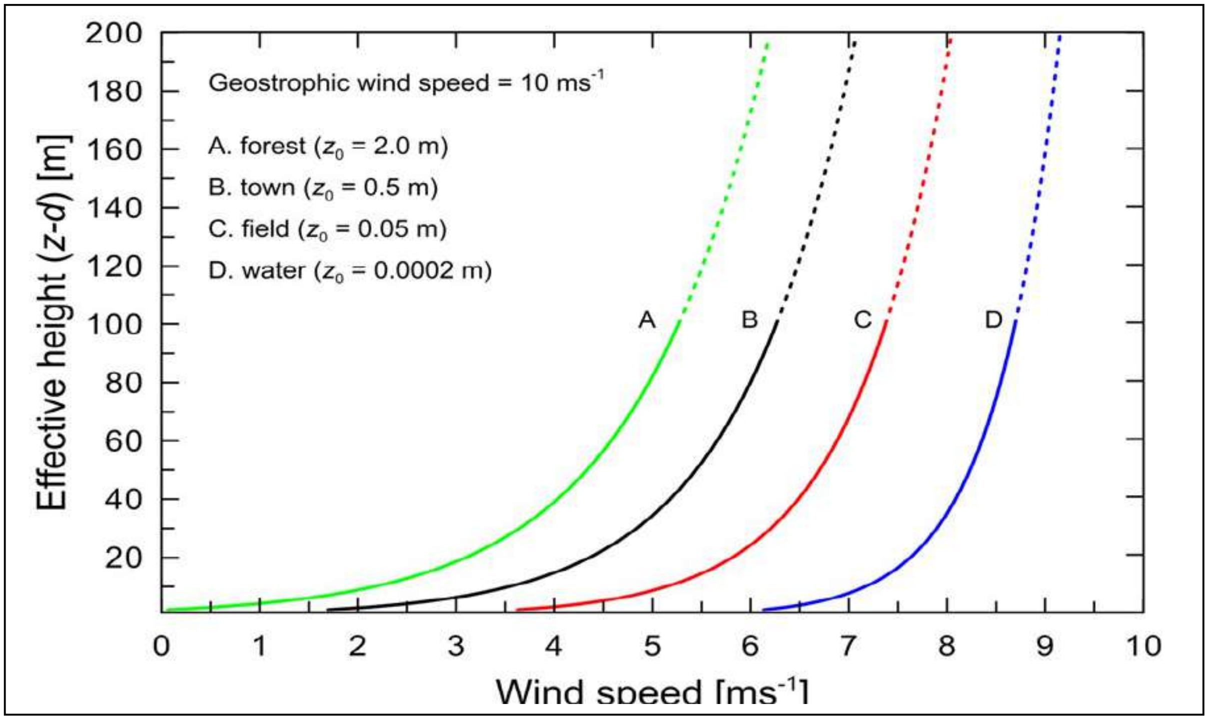


The vertical profile of wind speed upwind and on top of a hill. The speed-up is a function of height above the surface. The height of maximum speed up (l) is related to the geometry of the hill (L).

Surface roughness length is a property of the surface which can be used to determine the way the horizontal wind speed varies with height. The wind speed at a given height decreases with increasing surface roughness. It is very common to have a heterogeneous surface and this complicates the vertical wind profile. Internal boundary layers develop and the profile of wind speeds is influenced by surface roughness changes upwind.

Moving downwind of a surface roughness change, the wind speed profile does not change at all heights immediately downwind. At first, only the lowest parts of the profile change, with the change progressively reaching higher and higher with increasing downwind distance from the roughness change. The impact of a roughness change can be felt many kilometers downwind. As a rule of thumb, at 100 m above the terrain, a surface roughness change 10-km upwind may still have an influence on wind speed.

The WAsP roughness change model can account for these internal boundary layer effects due to inhomogeneous surface roughness.



Different surface roughness lengths result in different vertical profiles of wind speed. The y-axis is height above surface and the x-axis is wind speed. For a range of surface roughness lengths, the curves show the wind speed profile for neutral conditions and a geostrophic wind of 10 m/s.

The calculation system used for the GWA is called Frogfoot. It has been developed in association with the software development company World in a Box. The motivation for the development of Frogfoot is to allow high-resolution WAsP-like calculations of predicted wind climates to be made over large areas, using a large number of generalized wind climates. This need came because of numerical wind atlases being carried out on a nationwide-scale generated generalized wind climates on a grid with a spacing of, typically, 5-km.

As stated before, the Frogfoot system employs the same flow modeling as WAsP. Unlike the present WAsP, the terrain description can be input using raster maps, rather than vector maps. This is convenient for the GWA calculation because, typically, the global topographical data is in raster formats. Unlike the present WAsP, the starting point for describing the large-scale wind forcing is any number of geographically distributed generalized wind climates, whereas WAsP can only use one at a time.

The datasets used in the GWA 3.0 were chosen from the best available global datasets for each required category. This means the datasets needed to be both of high quality and have high enough resolution so that the downscaling process would not be missing large amounts of information.

Public datasets describing the earth's topography have become available at increased resolution in recent years. These impressive datasets make the GWA feasible. For the purpose of the GWA, the topography description can be split into two parts:

- ✓ the description of the surface elevation; referred to here as orography, as in the WAsP terminology
- ✓ the description of the surface land use or class

The GWA 3.0 combined the NASA Shuttle Radar Topography Mission (SRTM) elevation data with the digital elevation model (DEM) from Viewfinder Panoramas.

Void-filled SRTM data was used between 60°N and 60°S, with a few exceptions where the void filling process introduced artifacts that were not present in the Viewfinder Panoramas DEM.

North of 60°N the Viewfinder Panoramas DEM was used, allowing us to include model results for large parts of Scandinavia, Russia, and Canada. For these areas, the main sources to the Viewfinder Panoramas DEM are height contours from Russian military maps and Canadian Digital Elevation Data. The Viewfinder Panoramas DEM had several void regions which were filled using a cubic interpolation in the y-dimension of the raster. This was chosen after investigating many of the void regions and finding that they tended to run east-west.

Both DEM datasets were provided as 1° by 1° tiles in the WGS 1984 coordinate system (EPSG: 4326). To support the UTM projection used in the modeling, the data was re-projected to a 150m grid spacing using cubic interpolation. The interpolation was done using the Geospatial Data Abstraction Library (GDAL) tool gdalwarp. The 150m resolution was selected as it corresponds to the effective resolution of the SRTM data.
Land use to roughness length

Roughness length in GWA 3.0 was derived from the European Space Agency's Climate Change Initiative Land Cover (CCI-LC) dataset v2.0.7. This dataset was created for ESA by a large consortium, which included the Université Catholique de Louvain (UCL), who previously had made the Globcover 2009 land cover dataset that was used in GWA 1.0 and 2.0. Like Globcover, ESA CCI-LC was created by converting MERIS FR (Medium Resolution Imaging Spectrometer Instrument Fine Resolution) surface reflectance mosaics into land cover classes as based on the

United Nations Land Cover Classification System (LCCS). The ESA CCI-LC was selected, as it is a relatively recent land-cover map, with a consistent approach applied to all parts of the globe. It has a 10 arc-second (300 m) resolution and was provided in the WGS 1984 coordinate system (EPSG: 4326). The data was converted to the GWA tiles using nearest-neighbor interpolation, while retaining a spatial resolution of 300m.

While ESA CCI-LC is a full global raster, one of the classification types is no-data. This data type was found mostly in areas north of 60°. To void-fill these regions the 0.5 km MODIS-based Global Land Cover Climatology was used. This dataset is based on 10 years of data (2001-2010), and had 17 land cover classes. These classes were mapped to the GlobCover classes and then used to fill any no-data points.

Once the data was re-projected and the no-data points were filled, the data was converted to roughness length by defining a specific roughness length to each of the land use classes. For the GWA 3.0 an update to the conversion table was made, that reduced roughness lengths for many land-use categories. This was based in part on preliminary validation in South Africa, Vietnam, and Zambia.

Negative elevation data for seabed bathymetry was obtained from GEBCO's gridded bathymetric data set, the GEBCO_2020 grid, which is a global terrain model for ocean and land at 15 arc-second intervals. The GEBCO_2020 grid was prepared for use in the GWA by the World Bank Group.

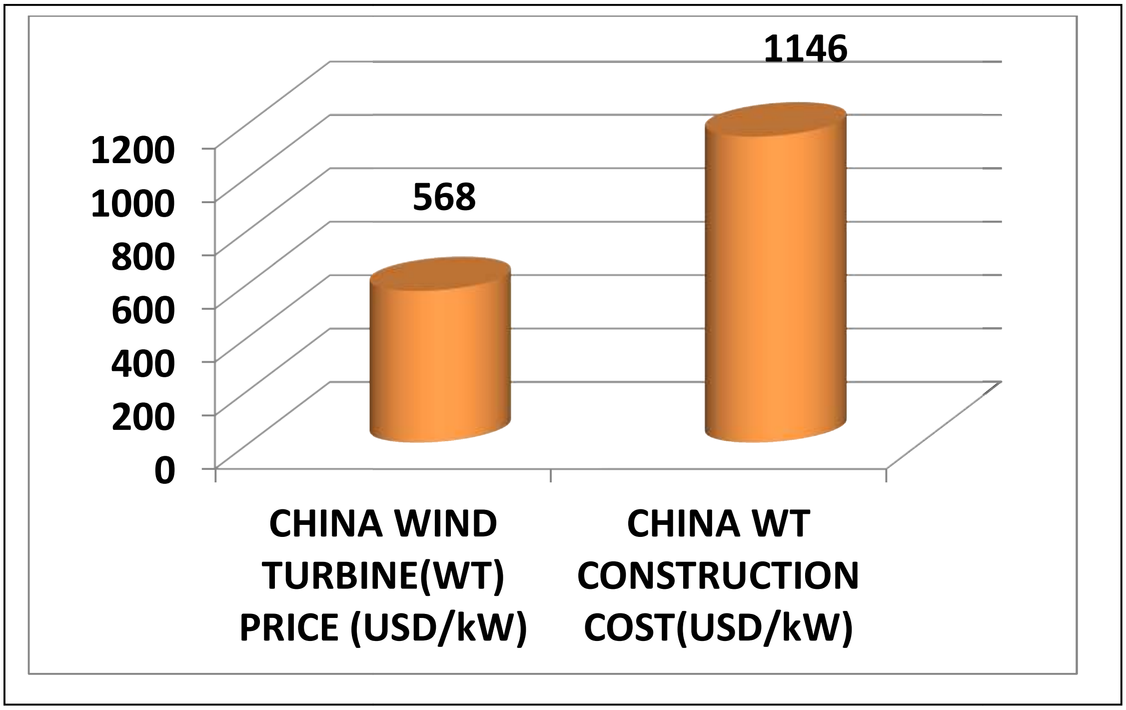
1.3. Trend of economical price of Offshore Wind Power Technology

"In the past decade, the LCOE of global onshore wind energy has fallen by about 25%, while the LCOE of onshore wind power in China has fallen by over 40%. By 2020, the on-grid price of wind farm projects can compete with that of coal-fired power projects and the on-grid price of PV projects will be reduced to the level of sales price set by the grid. Wind power is entering an era of grid parity," according to Goldwind Wind Power, at the 2019 China Wind Power Industry Innovation and Development Forum on May 22, 2019.

In the past 10 years, the efficiency of wind power generation in China has increased by 20% to 30%, the energy production has increased by 2% to 5%, and the operation and maintenance (O&M) cost has decreased by 5% to 10% through technological innovation such as high tower, airfoil optimization, independent pitch, cluster control, optimization of environmental control system, coating improvement and wind measurement technology.

In the past 20 years, with the help of technological innovation and scale effect, China's wind turbines price has fallen by 70%, to 3,550 yuan/kW = USD 568/kW; the cost of wind farm construction has dropped by 50%, to 7,160 yuan/kW = USD 1146/kW. The performance and reliability of power generation have been further improved.

Under the guidance of national policy, China's renewable energy will gradually achieve grid parity, its cost will even be lower than fossil fuel in the future, which is a common goal for renewable energy. According to the growing trend of energy, wind power will gradually transform from supplementary energy to alternative energy as it is renewable and its cost will decrease.



From the industrial point of view, the grid parity needs 2 to 3 years to materialize, which will be a reality in 2021.It is suggested to give more time to sort out the tiered pricing for grid parity, as the design and R&D of wind turbine as well as the costs of wind power supply chain have been locked.
In terms of wind resources and current construction cost, some provinces and cities like Shanghai and Fujian are ready, but further improvements in technology and business model are required if a nationwide grid parity or low price is to be in place.

After an overall analysis of wind power industry, Mr. Liu Rixi has put forward a path to grid parity for wind power: We need to change the business philosophy of wind power to prepare for grid parity, make systematic and customized solutions from technological innovation and model innovation, and get continued support from the government and the grid to jointly promote energy transformation. First, change the business philosophy.
1. Pay attention to the lifecycle LCOE from three aspects: increase energy production, reduce construction cost and reduce O&M cost.
2. Develop both centralized and distributed wind power projects. China has many policies and is rich in resources to support distributed wind power projects, whose locations overlaps with areas with developed economy and high electricity consumption.

Meanwhile, distributed wind power is not limited by the annual guided development scale and temporarily exempted from wind power bidding by 2020. It is closer to users and easier to utilize, thus it has greater market potential. It will be an important business model for developing user-side wind power in the era of grid parity.

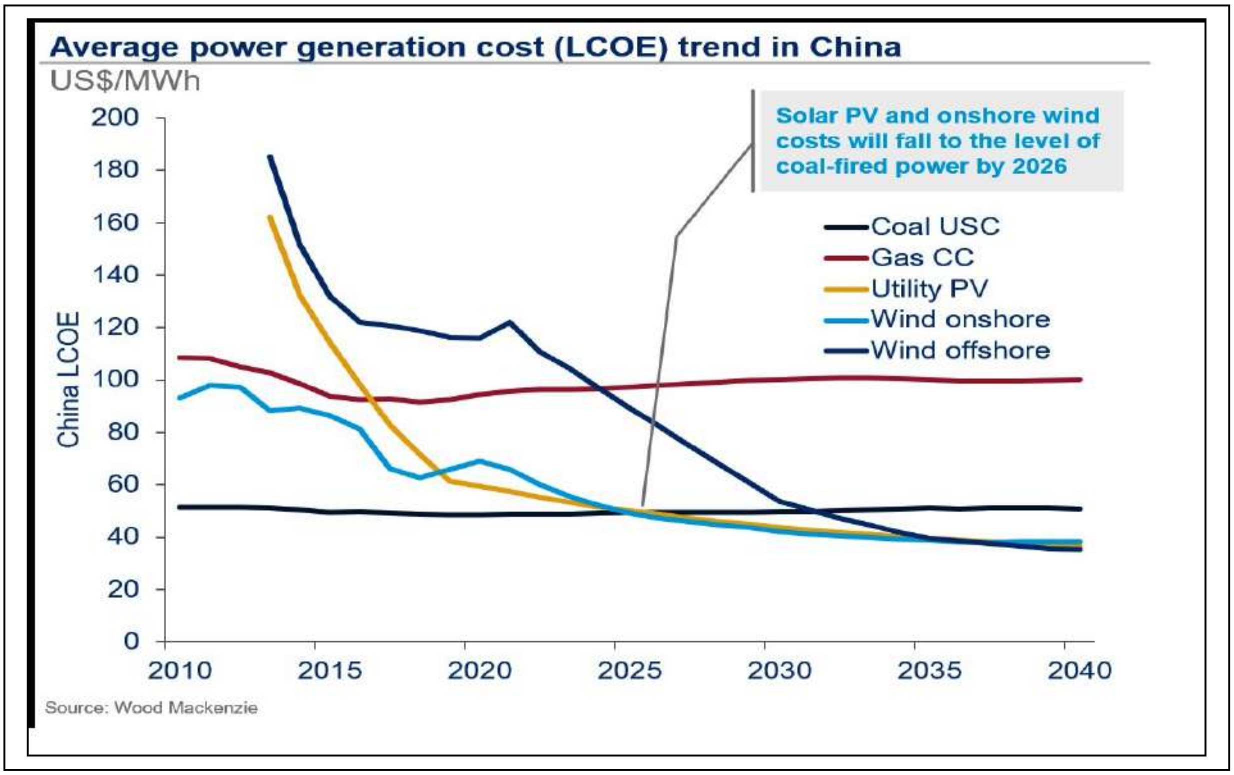
Second, technological innovation.

1. Achieve lifecycle optimization, from finding good resources, selecting high-yield wind turbines and refining early design at the planning and design stage, to the refined O&M, grid friendliness and risk management at the asset operation stage.

2. Reduce the LCOE by applying advanced technologies, power boost and other efficiency-improving solutions, other than lowering equipment price, so as to guard against the risk of low quality arising from low price.

3. Achieve integrated innovation of the wind power and energy value chain by applying digital technology.

Third, model innovation. Design customized business models for different application scenarios.

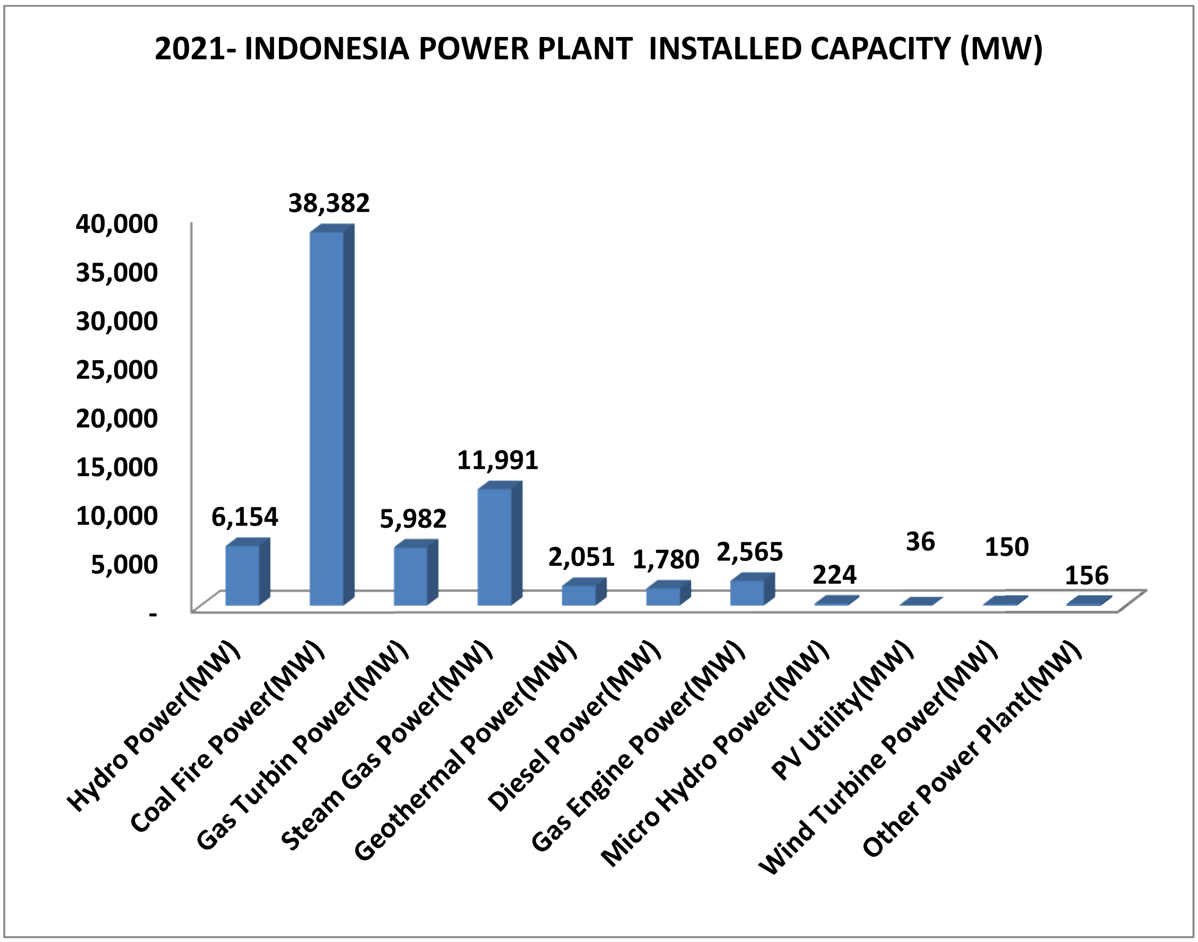


For example, provide comprehensive energy services that integrate distributed wind power, multi-energy complementation and smart energy; work with end users that have high electricity consumption and relatively low requirements for power quality, such as electrolytic aluminum company, so that end users can respond from the demand side, which can reduce the impact of wind power volatility on the grid.

Fourth, change the policy and the grid. Reduce non-technical costs and break the bottleneck on distributed power trading. Change the “one size fits all” approval process and reduce the policy costs of wind power (especially small-scale distributed wind power) development;

- ✓ Simplify the approval process of local distributed wind power projects, encourage the trial of project approval commitment system, and reduce the pre-project development costs;
- ✓ Further promote the market-oriented trading mechanism, break the bottleneck on distributed power trading, and reduce the transaction costs of enterprise users.
- ✓ Fifth, change the electricity users. Use price mechanism to encourage the response from the user side.
- ✓ While meeting the demand of the adjustable loads of electricity users, renewable energy can reduce its volatility. Encouraging the response from the use side helps to improve the power supply reliability of renewable energy.

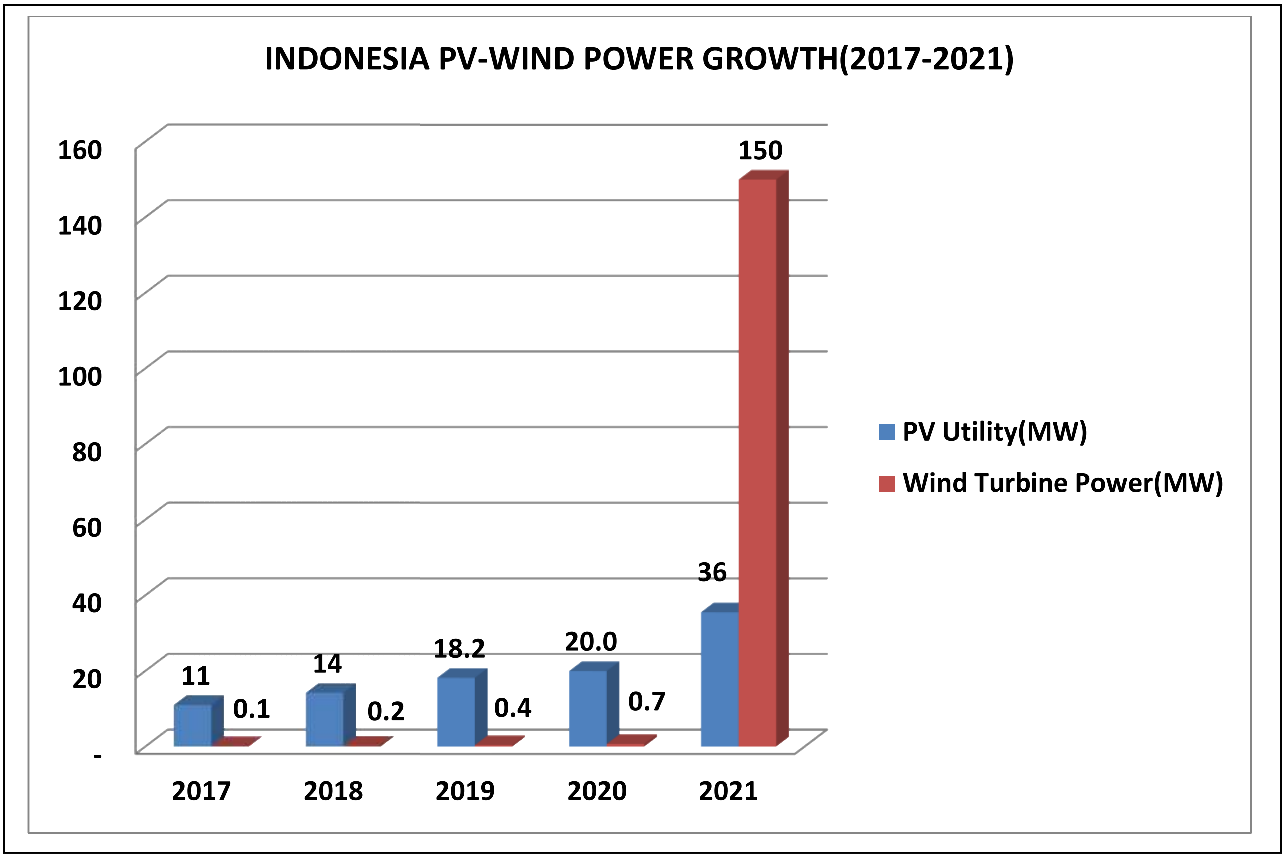
1.4. Projects demand



With target an economic growth rate of 5 percent in 2022, EBT electricity is expected to contribute to the projected growth in electricity demand in Java between 2017-2026 from 174 GWh to 326 GWh. With the opportunity given by the above government then our company would like to participate to encourage the utilization of renewable energy (EBT) as a source of electrical energy in the area of swampy swamp land including pond ponds and dry land so that this EBT electricity can suppress the use of fuel oil and common fossils and reduced CO2 emissions.

Utilization of renewable energy suitable offshore wind on grid capacity over 100 MW is a reliable solution for cheaper energy supply than diesel or fuel oil (BBM). In addition, maintenance and operation is also easy but gives significant impact to reduce pollution and greenhouse effect. Offshore wind turbine areas have their own advantages if built with large-scale capacity, such as easier and cheaper to integrate with existing electricity system, can utilize existing sea (reduce investment cost of land), and can help reduce the network load of existing systems. Offshore wind turbine system to be built is on grid. Assuming CO2 emission reduction of 0.891 kg / kWh in one year of production power plant 800 million kWh / year will be obtained emission reduction 712,800 tons CO2.

1.5. Benefit of Wind Project



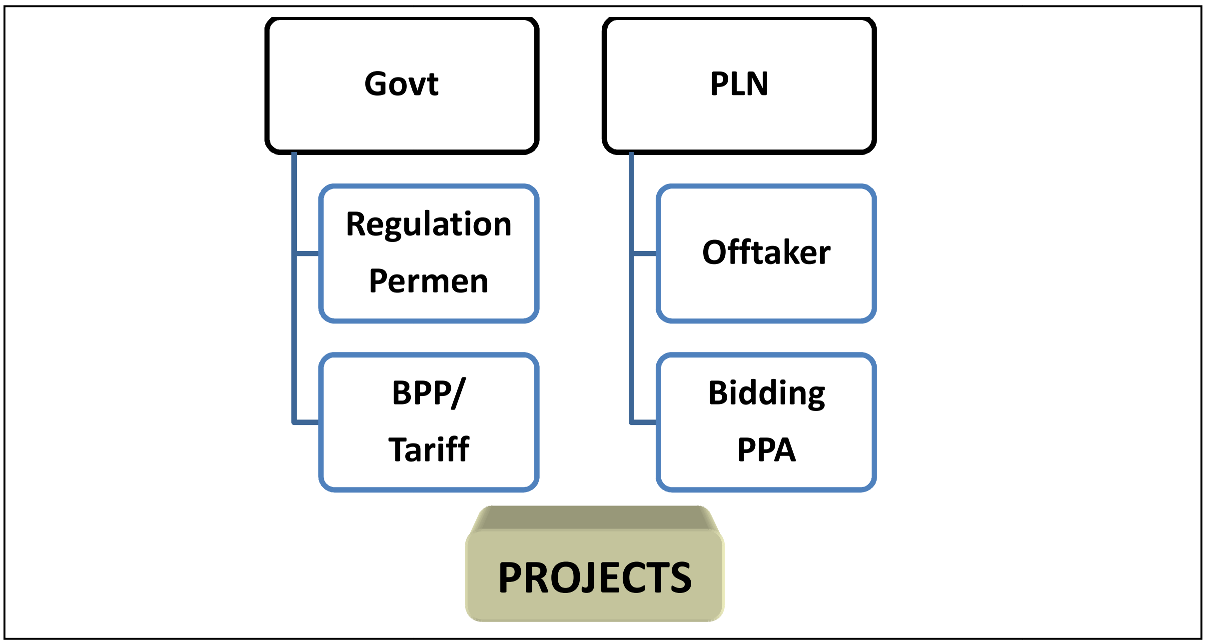
The advantage of locating wind turbines offshore is that the wind is much stronger off the coasts, and unlike wind over land, offshore breezes can be strong in the afternoon, matching the time when people are using the most electricity. Offshore turbines can also be located close to the load centers along the coasts, such as large cities, eliminating the need for new long-distance transmission lines. However, there are several disadvantages of offshore installations, related to more expensive installation, difficulty of access, and harsher conditions for the units. Locating wind turbines offshore exposes the units to high humidity, salt water and salt water spray which negatively affect service life, cause corrosion and oxidation, increase maintenance and repair costs and in general make every aspect of installation and operation much more difficult, time-consuming, more dangerous and far more expensive than sites on land. The humidity and temperature is controlled by air conditioning the sealed nacelle. Sustained high-speed operation and generation also increases wear, maintenance and repair requirements proportionally.

In Indonesia,the composition of EBT as of December 2016 is 12%, with a total of 6 GW of EBT generating the total power plant of 51.86 GW.

Proposal map 2017 (source : Rensis PLN) :

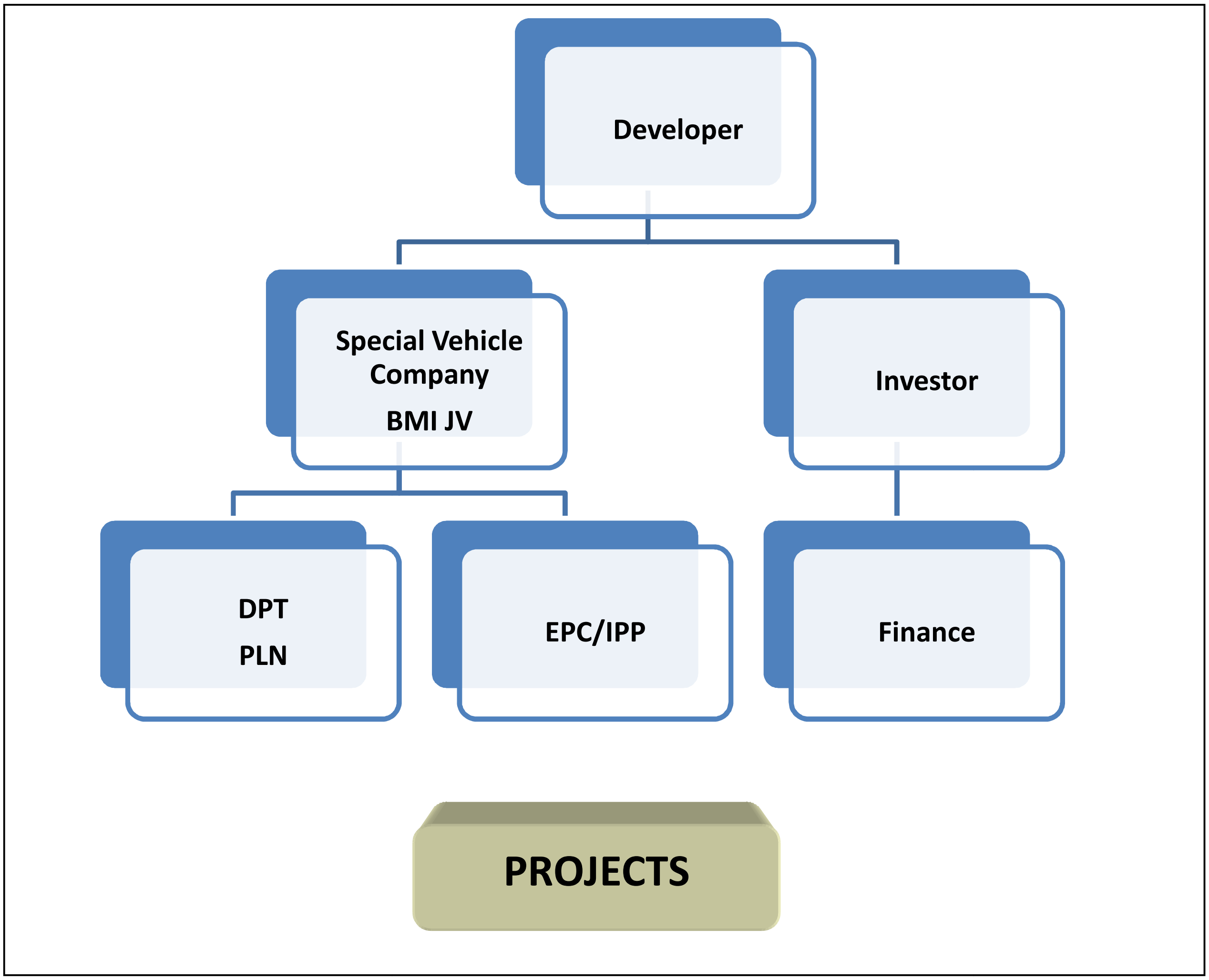
- ✓ Proposed PLTS 150 MW at West Java
- ✓ Total PLTS = 572 MW→ Jawa-Bali = 275 MW
- ✓ Total PLT Wind = 1345 MW → Jawa-Bali = 490 MW
- ✓ Total PLT Hybrid = 120 MW
- ✓ Total PLT biomassa = 1 MW

1.5. Project parties (Owner, PLN,Government,Investor,etc)



Remarks :

- ➢ Govt issued Regulation and Tariff BPP
- ➢ Client = PT PLN (Persero) as offtaker issued Bidding/PPA
- ➢ Developer = Owner
- ➢ Investor brings finance and technology provider
- ➢ EPC Contractor / IPP = DPT company Joint Venture with Technology Provider


Developer
Special Vehicle Company
BMI JV
Investor
DPT
PLN
EPC/IPP
Finance
PROJECTS

Chapter 2. Description of Technology of offshore wind turbine

2.1.Offshore wind turbine for electricity power generation

Largest offshore wind turbines are under construction :

No	Offshore Wind Turbine	Country	MW	Wind Turbine	Target COD
1	Hollandse Kust Zuid I-IV	Netherlands	1.540	140 × Siemens Gamesa 11MW	2023
2	Hornsea Project 2	United Kingdom	1.386	165 Siemens Gamesa 8MW SG 8.0-167 DD	2022-2023
3	Dogger Bank A	United Kingdom	1.200	95 x GE Haliade-X 13MW	2023
4	Dogger Bank B	United Kingdom	1.200	95 x GE Haliade-X 13MW	2023-2026
5	Seagreen (Alpha & Bravo)	United Kingdom	1.075	114 x MHI Vestas V164-10 MW	2024
6	Moray East	United Kingdom	950	100 x MHI Vestas V164 9.5 MW	2021
7	Greater Changhua	Taiwan	900	111 x Siemens Gamesa 8MW-167 DD	2022
8	Triton Knoll	United Kingdom	855	90 x MHI Vestas 9.5 MW	2021
9	The Neart na Gaoithe (NnG)	United Kingdom	450	54 Siemens Gamesa SG 8.0-167 DD	2023
10	CTGNE Yangjiang Shapa - phase II	China	400	Mingyang MySE6.45-180	2021
11	Rudong H6	China	400	100 x G4-146	2021
12	Formosa II	Taiwan	376	47 × Siemens Gamesa 8MW-167 DD	2021

As of 2020, the total worldwide offshore wind power capacity was 35.3 gigawatt (GW). United Kingdom (29%), China (28%) and Germany (22%) account for more than 75% of the global installed capacity. The 1.2 GW Hornsea Project One in the United Kingdom was the world's largest offshore wind farm. Other projects in the planning stage include Dogger Bank in the United Kingdom at 4.8 GW, and Greater Changhua in Taiwan at 2.4 GW.

Unlike the typical use of the term "offshore" in the marine industry, offshore wind power includes inshore water areas such as lakes, fjords and sheltered coastal areas as well as deeper-water areas. Most offshore wind farms employ fixed-foundation wind turbines in relatively shallow water. As of 2020, floating wind turbines for deeper waters were in the early phase of development and deployment.

The cost of offshore has historically been higher than that of onshore, but costs decreased to $78/MWh in 2019. Offshore wind power in Europe became price-competitive with conventional power sources in 2017. Offshore wind generation grew at over 30 percent per year in the 2010s. As of 2020, offshore wind power had become a significant part of northern Europe power generation, though it remained less than 1 percent of overall world electricity generation.

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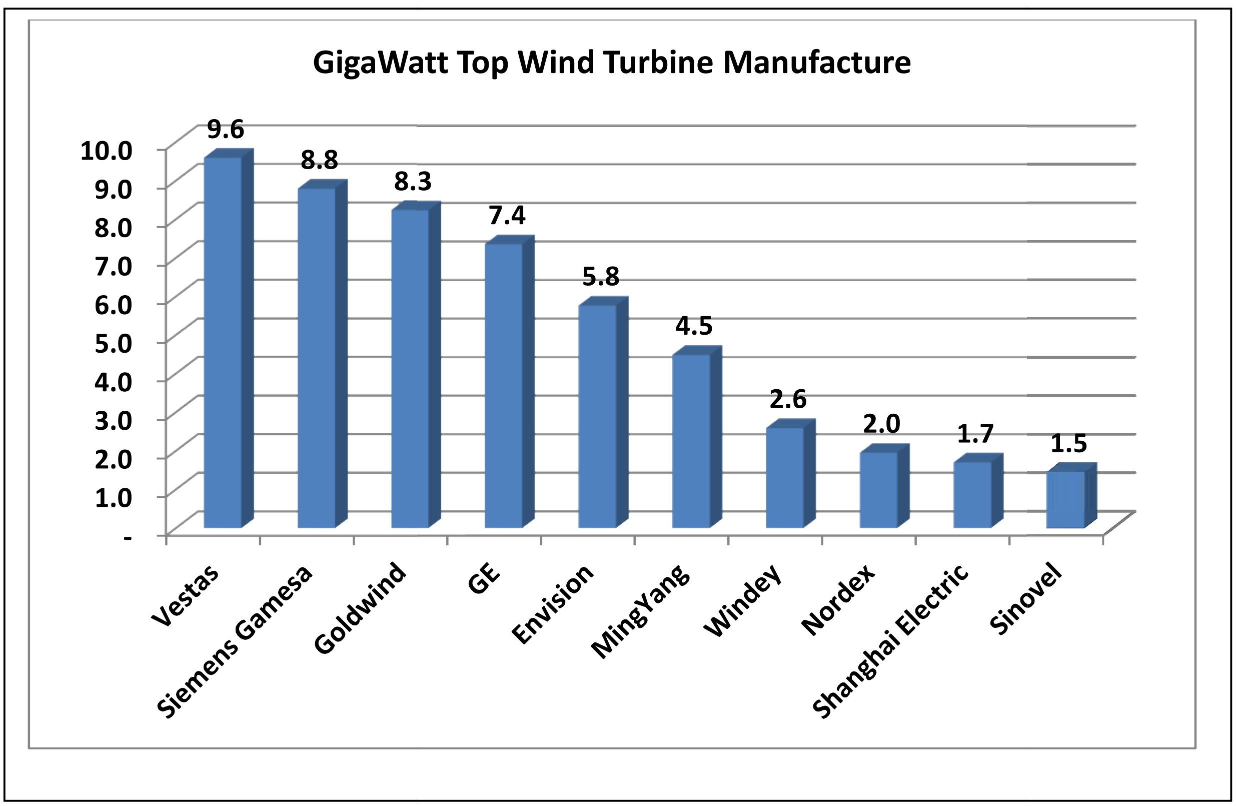
2.2. Global wind turbine market

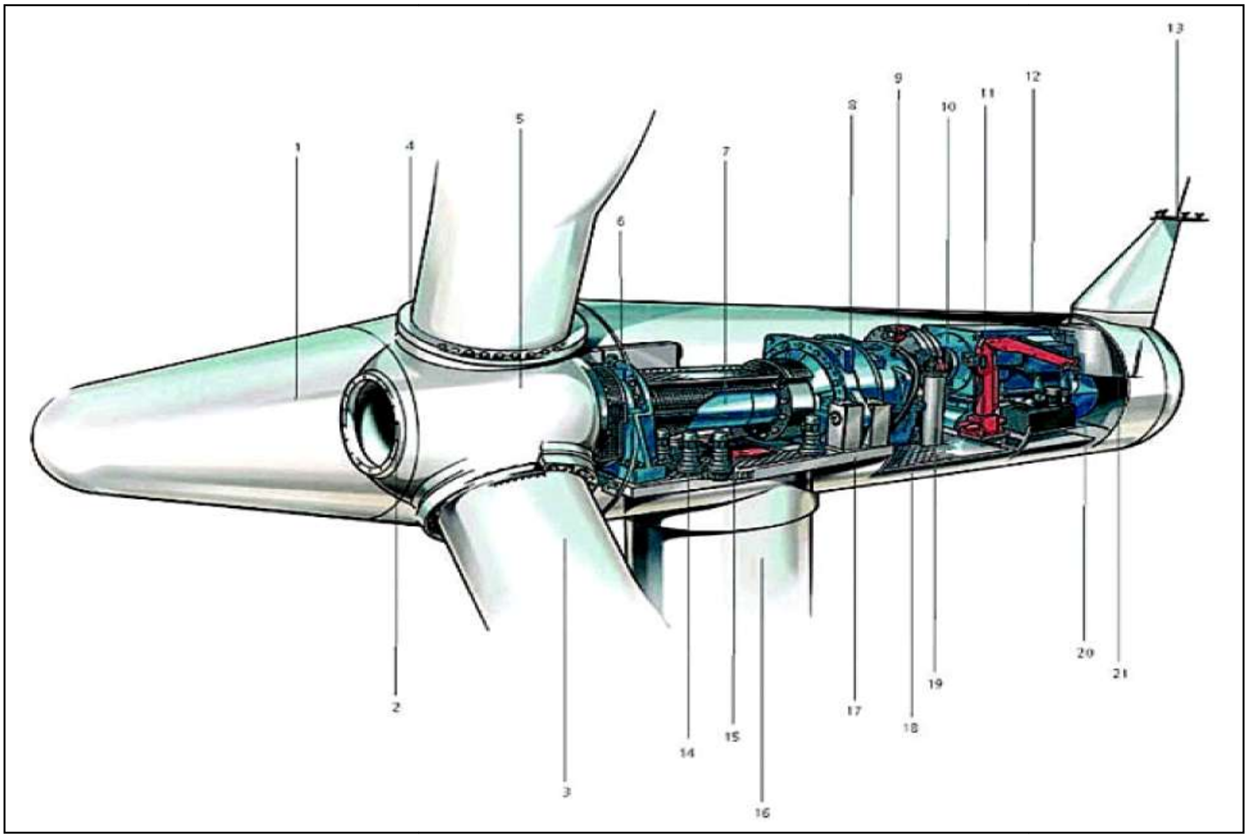
In 2021, there are 10 top global producers of wind turbines:

No	Manufacture	City Country	GigaWatt
1	Vestas	Aarhus, Denmark	9,6
2	Siemens Gamesa	Biscay, Spain	8,8
3	Goldwind	Beijing, China	8,3
4	GE	Boston, U.S.	7,4
5	Envision	Shanghai, China	5,8
6	MingYang	Zhongshan, China	4,5
7	Windey	Zhejiang, China	2,6
8	Nordex	Hamburg, Germany	2,0
9	Shanghai Electric	Shanghai, China	1,7
10	Sinovel	Chongqin, China	1,5

The Danish wind turbine manufacturer Vestas is currently the world's largest wind turbine maker, representing over 16% of the world wind turbine market.



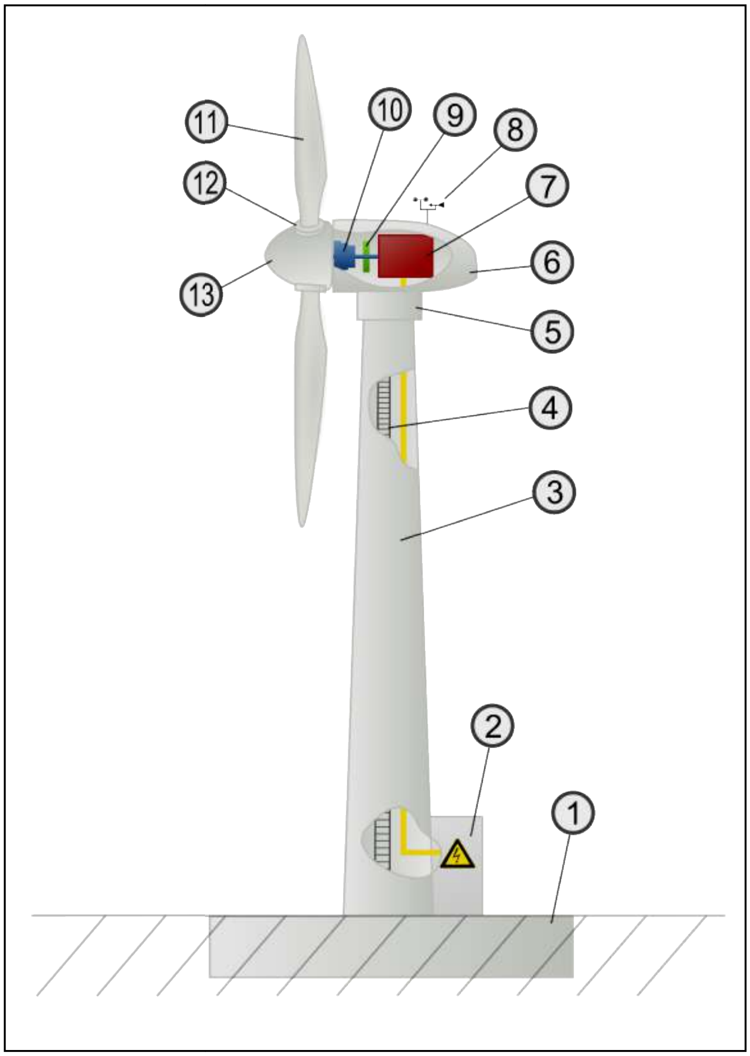
2.3.Specification of wind turbine technology



Parts are :

1. Spinner	8. Gearbox	15. Yaw ring
2. Spinner bracket	9. Brake disc	16. Tower
3. Blade	10. Coupling	17. Nacelle bedplate
4. Pitch bearing	11. Service crane	18. Canopy
5. Rotor hub	12. Generator	19. Oil filter
6. Main bearing	13. Meteorological sensors	20. Generator fan
7. Main shaft	14. Yaw gear	21. Oil cooler

The turbine represents the best of the qualities for which we are known throughout the wind industry – an efficient and reliable machine combining a solid and conservative design approach with high-performance technical features, such as the unique CombiStall® power regulation system and IntegralBlade® technology. The SWT-2.3-82 wind turbine is equally well suited for tough and demanding applications onshore and offshore. One of the projects featuring the turbine is the Nysted Offshore Wind Farm – at the time of installation the world's largest farm.



Wind turbine components : 1-Foundation, 2-Connection to the electric grid, 3-Tower, 4-Access ladder, 5-Wind orientation control (Yaw control), 6-Nacelle, 7-Generator, 8-Anemometer, 9-Electric or Mechanical Brake, 10-Gearbox, 11-Rotor blade, 12-Blade pitch control, 13-Rotor hub.

Wind turbine design is the process of defining the form and configuration of a wind turbine to extract energy from the wind. An installation consists of the systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine.

In 1919, German physicist Albert Betz showed that for a hypothetical ideal wind-energy extraction machine, the fundamental laws of conservation of mass and energy allowed no more than 16/27 (59.3%) of the wind's kinetic energy to be captured. This Betz' law limit can be approached modern turbine designs which reach 70 to 80% of this theoretical limit. In addition to the blades, design of a complete wind power system must also address the hub, controls, generator, supporting structure and foundation. Turbines must also be integrated into power grids. Blade shape and dimension are determined by the aerodynamic performance required to efficiently extract energy, and by the strength required to resist forces on the blade. The aerodynamics of a horizontal-axis wind turbine are not straightforward. The air flow at the blades is not the same as that away from the turbine. The way that energy is extracted from the air also causes air to be deflected by the turbine. Wind turbine aerodynamics at the rotor surface exhibit phenomena that are rarely seen in other aerodynamic fields.

Rotation speed must be controlled for efficient power generation and to keep the turbine components within speed and torque limits. The centrifugal force on the blades increases as the square of the rotation speed, which makes this structure sensitive to overspeed. Because power increases as the cube of the wind speed, turbines have must survive much higher wind loads (such as gusts of wind) than those loads from which they generate power. A wind turbine must produce power over a range of wind speeds. The cut-in speed is around 3–4 m/s for most turbines, and cut-out at 25 m/s. If the rated wind speed is exceeded the power has to be limited. A control system involves three basic elements: sensors to measure process variables, actuators to manipulate energy capture and component loading, and control algorithms that apply information gathered by the sensors to coordinate the actuators. Any wind blowing above the survival speed damages the turbine. The survival speed of commercial wind turbines ranges from 40 m/s (144 km/h, 89 MPH) to 72 m/s (259 km/h, 161 MPH), typically around 60 m/s (216 km/h, 134 MPH). Some turbines can survive 80 metres per second (290 km/h; 180 mph). A stall on an airfoil occurs when air passes over it in such a way that the generation of lift rapidly decreases. Usually this is due to a high angle of attack (AOA), but can also result from dynamic effects. The blades of a fixed pitch turbine can be designed to stall in high wind speeds, slowing rotation. This is a simple fail-safe mechanism to help prevent damage. However, other than systems with dynamically controlled pitch, it can not produce a constant power output over a large range of wind speeds, which makes it less suitable for large scale, power grid applications. A fixed-speed HAWT inherently increases its angle of attack at higher wind speed as the blades speed up. A natural strategy, then, is to allow the blade to stall when the wind speed increases. This technique was successfully used on many early HAWTs. However, the degree of blade pitch tended to increase noise levels. Vortex generators may be used to control blade lift characteristics. VGs are placed on the airfoil to enhance the lift if they are placed on the lower (flatter) surface or limit the maximum lift if placed on the upper (higher camber) surface. Furling works by decreasing the angle of attack, which reduces drag and blade cross-section. One major problem is getting the blades to stall or furl quickly enough in a wind gust. A fully furled turbine blade, when stopped, faces the edge of the blade into the wind. Loads can be reduced by making a structural system softer or more flexible. This can be accomplished with downwind rotors or with curved blades that twist naturally to reduce angle of attack at higher wind speeds. These systems are nonlinear and couple the structure to the flow field - requiring design tools to evolve to model these nonlinearities. Standard turbines all furl in high winds. Since furling requires acting against the torque on the blade, it requires some form of pitch angle control, which is achieved with a slewing drive. This drive precisely angles the blade while withstanding high torque loads. In addition, many turbines use hydraulic systems. These systems are usually spring-loaded, so that if hydraulic power fails, the blades automatically furl. Other turbines use an electric servomotor for every blade. They have a battery-reserve in case of grid failure. Small wind turbines (under 50 kW) with variable-pitching generally use systems operated by centrifugal force, either by flyweights or geometric design, and avoid electric or hydraulic controls. Fundamental gaps exist in pitch control, limiting the reduction of energy costs, according to a report funded by the Atkinson Center for a Sustainable Future. Load reduction is currently focused on full-span blade pitch control, since individual pitch motors are the actuators on commercial turbines. Significant load mitigation has been demonstrated in simulations for blades, tower, and drive train. However, further research is needed to increase energy capture and mitigate fatigue loads. A control technique applied to the pitch angle is done by comparing the power output with the power value at the rated engine speed (power reference, Ps reference). Pitch control is done with PI controller. In order to adjust pitch rapidly enough, the actuator uses the time constant Tservo, an integrator and limiters. The pitch angle remains from 0° to 30° with a change rate of 10°/second. Modern large wind turbines operate at variable speeds. When wind speed falls below the turbine's rated speed, generator torque is used to control the rotor speed to capture as much power as possible. The most power is captured when the tip speed ratio is held constant at its optimum value (typically 6 or 7). This means that rotor speed increases proportional to wind speed. The difference between the aerodynamic torque captured by the blades and the applied generator torque controls the rotor speed. If the generator torque is lower, the rotor accelerates, and if the generator torque is higher, the rotor slows. Below rated wind speed, the generator torque control is active while the blade pitch is typically held at the constant angle that captures the most power, fairly flat to the wind. Above rated wind speed, the generator torque is typically held constant while the blade pitch is adjusted accordingly. One technique to control a permanent magnet synchronous motor is field-oriented control. Field-oriented control is a closed loop strategy composed of two current controllers (an inner loop and cascading outer loop) necessary for controlling the torque, and one speed controller.

Large turbines are typically actively controlled to face the wind direction measured by a wind vane situated on the back of the nacelle. By minimizing the yaw angle (the misalignment between wind and turbine pointing direction), power output is maximized and non-symmetrical loads minimized. However, since wind direction varies, the turbine does not strictly follow the wind and experiences a small yaw angle on average. The power output losses can be approximated to fall with (cos(yaw angle))3. Particularly at low-to-medium wind speeds, yawing can significantly reduce output, with wind common variations reaching 30°. At high wind speeds, wind direction is less variable.

In conventional wind turbines, the blades spin a shaft that is connected through a gearbox to the generator. The gearbox converts the turning speed of the blades (15 to 20 RPM for a one-megawatt turbine) into the 1,800 (750-3600) RPM that the generator needs to generate electricity. Analysts from Global Data estimate that the gearbox market grew from $3.2bn in 2006 to $6.9bn in 2011. The market leader was Winergy in 2011. The use of magnetic gearboxes has been explored as a way of reducing maintenance costs.

For large horizontal axis wind turbines (HAWT), the generator is mounted in a nacelle at the top of a tower, behind the rotor hub. Older wind turbines generate electricity through asynchronous machines directly connected to the grid. The gearbox reduces generator cost and weight. Commercial generators have a rotor carrying a winding so that a rotating magnetic field is produced inside a set of windings called the stator. While the rotating winding consumes a fraction of a percent of the generator output, adjustment of the field current allows good control over the output voltage. The rotor's varying output frequency and voltage can be matched to the fixed values of the grid using multiple technologies such as doubly fed induction generators or full-effect converters which converts the variable frequency current to DC and then back to AC using inverters. Although such alternatives require costly equipment and cost power, the turbine can capture a significantly larger fraction of the wind energy. Most are Low Voltage 660 Volt, but some offshore turbines (several MW) are 3.3 kV Medium Voltage. In some cases, especially when offshore, a large collector transformer converts the wind farm's medium-voltage AC grid to DC and transmits the energy through a power cable to an onshore HVDC converter station.

The ratio between the blade speed and the wind speed is called tip-speed ratio. High efficiency 3-blade-turbines have tip speed/wind speed ratios of 6 to 7. Wind turbines spin at varying speeds (a consequence of their generator design). Use of aluminum and composite materials has contributed to low rotational inertia, which means that newer wind turbines can accelerate quickly if the winds pick up, keeping the tip speed ratio more nearly constant. Operating closer to their optimal tip speed ratio during energetic gusts of wind allows wind turbines to improve energy capture from sudden gusts. Noise increases with tip speed. To increase tip speed without increasing noise would reduce torque into the gearbox and generator, reducing structural loads, thereby reducing cost. The noise reduction is linked to the detailed blade aerodynamics, especially factors that reduce abrupt stalling. The inability to predict stall restricts the use of aggressive aerodynamics. Some blades (mostly on Enercon) have a winglet to increase performance and reduce noise. A blade can have a lift-to-drag ratio of 120, compared to 70 for a sailplane and 15 for an airline. In general, materials should meet the following criteria:

- wide availability and easy processing to reduce cost and maintenance
- low weight or density to reduce gravitational forces
- high strength to withstand wind and gravitational loading
- high fatigue resistance to withstand cyclic loading
- high stiffness to ensure stability of the optimal shape and orientation of the blade and clearance with the tower
- high fracture toughness
- the ability to withstand environmental impacts such as lightning strikes, humidity, and temperature

Metals are undesirable because of their vulnerability to fatigue. Ceramics have low fracture toughness, resulting in early blade failure. Traditional polymers are not stiff enough to be useful, and wood has problems with repeatability, especially considering the blade length. That leaves fiber-reinforced composites, which have high strength and stiffness and low density. Wood and canvas sails were used on early windmills due to their low price, availability, and ease of manufacture. Smaller blades can be made from light metals such as aluminium. These materials, however, require frequent maintenance. Wood and canvas construction limits the airfoil shape to a flat plate, which has a relatively high ratio of drag to force captured(low aerodynamic efficiency) compared to solid airfoils. Construction of solid airfoil designs requires inflexible materials such as metals or composites. Some blades incorporate lightning conductors. Increasing blade length pushed power generation from the single megawatt range to upwards of 10 megawatts. A larger area effectively increases tip-speed ratio at a given wind speed, thus increasing its energy extraction. Software such as HyperSizer (originally developed for spacecraft design) can be used to improve blade design.

As of 2015 the rotor diameters of onshore wind turbine blades reached 130 meters, while the diameter of offshore turbines reached 170 meters. In 2001, an estimated 50 million kilograms of fiberglass laminate were used in wind turbine blades. An important goal is to control blade weight. Since blade mass scales as the cube of the turbine radius, gravity loading constrains systems with larger blades.Gravitational loads include axial and tensile/ compressive loads (top/bottom of rotation) as well as bending (lateral positions).The magnitude of these loads fluctuates cyclically and the edgewise moments (see below) are reversed every 180° of rotation. Typical rotor speeds and design life are ~10 and 20 years, respectively, with the number of lifetime revolutions on the order of 10^8. Considering wind, it is expected that turbine blades go through ~10^9 loading cycles.

Wind is another source of rotor blade loading. Lift causes bending in the flatwise direction (out of rotor plane) while airflow around the blade cause edgewise bending (in the rotor plane). Flaps bending involves tension on the pressure (upwind) side and compression on the suction (downwind) side. Edgewise bending involves tension on the leading edge and compression on the trailing edge. Wind loads are cyclical because of natural variability in wind speed and wind shear (higher speeds at top of rotation). Failure in ultimate loading of wind-turbine rotor blades exposed to wind and gravity loading is a failure mode that needs to be considered when the rotor blades are designed. The wind speed that causes bending of the rotor blades exhibits a natural variability, and so does the stress response in the rotor blades. Also, the resistance of the rotor blades, in terms of their tensile strengths, exhibits a natural variability. In light of these failure modes and increasingly larger blade systems, researchers seek cost-effective materials with higher strength-to-mass ratios.

The majority of commercialized wind turbine blades are made from fiber-reinforced polymers (FRPs), which are composites consisting of a polymer matrix and fibers. The long fibers provide longitudinal stiffness and strength, and the matrix provides fracture toughness, delamination strength, out-of-plane strength, and stiffness.Material indices based on maximizing power efficiency, high fracture toughness, fatigue resistance, and thermal stability are highest for glass and carbon fiber reinforced plastics (GFRPs and CFRPs). In turbine blades, matrices such as thermosets or thermoplastics are used, although the former more common.These allow for the fibers to be bound together and add toughness. Thermosets make up 80% of the market, as they allow for low temperature cure, and lower viscosity, combining for easy processing. Thermoplastics offer recyclability that the thermosets do not, however, the processing temperature and viscosity are much higher, limiting the size and consistency that is important for large blades. Fracture toughness is higher for thermoplastics, but the fatigue behavior is worse

Manufacturing blades in the 40 to 50-metre range involves proven fiberglass composite fabrication techniques. Manufactures such as Nordex SE and GE Wind use an infusion process. Other manufacturers vary this technique, some including carbon and wood with fiberglass in an epoxy matrix. Other options include pre-impregnated ("prepreg") fiberglass and vacuum-assisted resin transfer moulding. Each of these options use a glass-fiber reinforced polymer composite constructed with differing complexity. Perhaps the largest issue with open-mould, wet systems are the emissions associated with the volatile organics released. Preimpregnated materials and resin infusion techniques avoid the release of volatiles by containing all VOCs. These contained processes have their challenges, because the production of thick laminates necessary for structural components becomes more difficult. The preform resin permeability dictates the maximum laminate thickness, bleeding is required to eliminate voids and ensure proper resin distribution. One solution to resin distribution is partially impregnated fiberglass.

During evacuation, the dry fabric provides a path for airflow and, once heat and pressure are applied, the resin may flow into the dry region resulting in an evenly impregnated laminate structure.

Epoxy-based composites have environmental, production, and cost advantages over other resin systems. Epoxies also allow shorter cure cycles, increased durability, and improved surface finish. Prepreg operations further reduce processing time over wet lay-up systems. As turbine blades passed 60 metres, infusion techniques became more prevalent, because traditional resin transfer moulding injection times are too long compared to resin set-up time, limiting laminate thickness. Injection forces resin through a thicker ply stack, thus depositing the resin in the laminate structure before gelation occurs. Specialized epoxy resins have been developed to customize lifetimes and viscosity. Carbon fiber-reinforced load-bearing spars can reduce weight and increase stiffness. Using carbon fibers in 60-metre turbine blades is estimated to reduce total blade mass by 38% and decrease cost by 14% compared to 100% fiberglass. Carbon fibers have the added benefit of reducing the thickness of fiberglass laminate sections, further addressing the problems associated with resin wetting of thick lay-up sections. Wind turbines benefit from the trend of decreasing carbon fiber costs.

Although glass and carbon fibers have many optimal qualities, their downsides include the fact that high filler fraction (10-70 wt%) causes increased density as well as microscopic defects and voids that can lead to premature failure. Carbon nanotubes (CNTs) can reinforce polymer-based nanocomposites. CNTs can be grown or deposited on the fibers or added into polymer resins as a matrix for FRP structures. Using nanoscale CNTs as filler instead of traditional microscale filler (such as glass or carbon fibers) results in CNT/polymer nanocomposites, for which the properties can be changed significantly at low filler contents (typically < 5 wt%). They have low density and improve the elastic modulus, strength, and fracture toughness of the polymer matrix. The addition of CNTs to the matrix also reduces the propagation of interlaminar cracks.

Current research on a low-cost carbon fiber (LCCF) at Oak Ridge National Laboratory gained attention as it can mitigate the structural damage from lightning strikes. On glass fiber wind turbines, lightning strike protection (LSP) is usually added on top, but this is effectively deadweight in terms of structural contribution. Conductive carbon fiber can remove this , especially as carbon fiber is a better material, would be ideal. Some polymer composites feature self-healing properties. Self-healing polymers are attractive for this application, as the blades of the turbine form cracks from fatigue due to repetitive cyclic stresses and can thus improve reliability and buffer various defects such as delamination. The polymer heals the cracks as they form. Paraffin wax-coated copper wires embedded in a fiber reinforced polymer create a network of tubes. Using these tubes, dicyclopentadiene (DCPD) and a catalyst, then react to form a thermosetting polymer, which repairs the cracks that form in the material. This approach is not yet commercial.

Further improvement is possible through the use of carbon nanofibers (CNFs) in the blade coatings. A major problem in desert environments is erosion of the leading edges of blades by sand-laden wind, which increases roughness and decreases aerodynamic performance. The particle erosion resistance of fiber-reinforced polymers is poor when compared to metallic materials and elastomers. Replacing glass fiber with CNF on the composite surface greatly improves erosion resistance. CNFs provide good electrical conductivity (important for lightning strikes), high damping ratio, and good impact-friction resistance.

For wind turbines, especially those offshore, or in wet environments, base surface erosion also occurs. For example, in cold climates, ice can build up on the blades and increase roughness. At high speeds, this same erosion impact can occur from rainwater. A useful coating must have good adhesion, temperature tolerance, weather tolerance (to resist erosion from salt, rain, sand, etc.), mechanical strength, ultraviolet light tolerance, and have anti-icing and flame retardant properties. Along with this, the coating should be cheap and environmentally friendly.

Lightning damage over the course of a 25-year lifetime goes from surface level scorching and cracking of the laminate material, to ruptures in the blade or full separation in the adhesives that hold the blade together. It is most common to observe lightning strikes on the tips of the blades, especially in rainy weather due to embedded copper wiring. The most common method countermeasure, especially in non-conducting blade materials like GFRPs and CFRPs, is to add lightning "arresters", which are metallic wires that ground the blade, skipping the blades and gearbox entirely.

The Global Wind Energy Council (GWEC) predicted that wind energy will supply 28.5% of global energy by 2030. This requires a newer and larger fleet of more efficient turbines and the corresponding decommissioning of older ones. Based on a European Wind Energy Association study, in 2010 between 110 and 140 kilotons of composites were consumed to manufacture blades. The majority of the blade material ends up as waste, and requires recycling. As of 2020, most end-of-use blades are stored or sent to landfills rather than recycled. Typically, glass-fiber-reinforced-polymers (GFRPs) compose of around 70% of the laminate material in the blade. GFRPs hinder incineration and are not combustible. Therefore, conventional recycling methods is inappropriate. Depending on whether individual fibers can be recovered, GFRP recycling involves:

Mechanical Recycling: This method doesn't recover individual fibers. Initial processes involve shredding, crushing, or milling. The crushed pieces are then separated into fiber-rich and resin-rich fractions. These fractions are ultimately incorporated into new composites either as fillers or reinforcements.

Chemical Processing/Pyrolysis: Thermal decomposition of the composites recovers individual fibers. For pyrolysis, the material is heated up to 500 °C in an environment without oxygen, thus causing it to break down into lower weight organic substances and gaseous products. The glass fibers generally lose 50% of their strength and can be downcycled for fiber reinforcement applications in paints or concrete. This can recover up to approximately 19 MJ/kg at relatively high cost. It requires similar mechanical pre-processing.

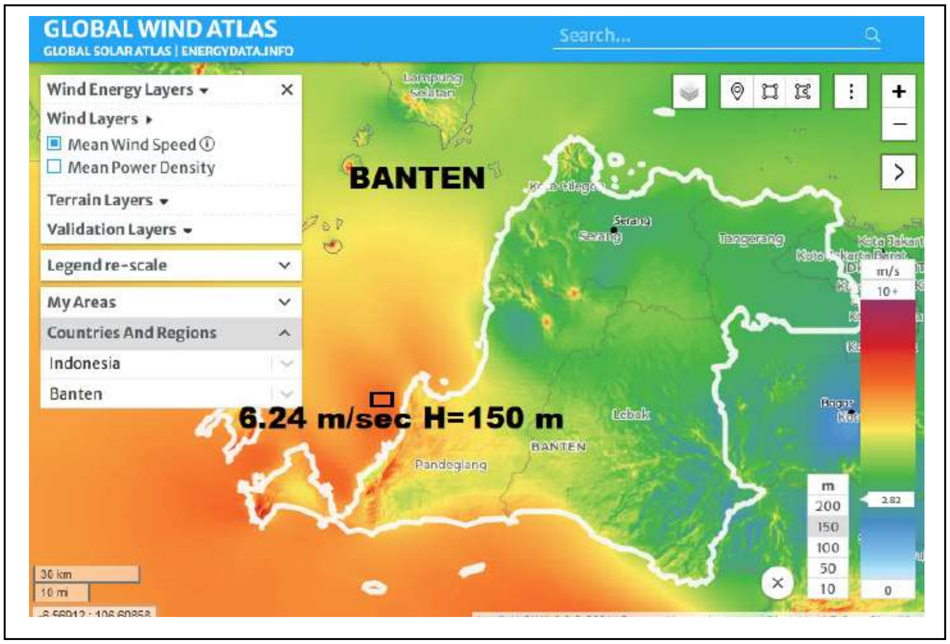
Wind velocities increase at higher altitudes due to surface aerodynamic drag (by land or water surfaces) and air viscosity. The variation in velocity with altitude, called wind shear, is most dramatic near the surface. Typically, the variation follows the wind profile power law, which predicts that wind speed rises proportionally to the seventh root of altitude. Doubling the altitude of a turbine, then, increases the expected wind speeds by 10% and the expected power by 34%. To avoid buckling, doubling the tower height generally requires doubling the tower diameter, increasing the amount of material by a factor of at least four.

During the night, or when the atmosphere becomes stable, wind speed close to the ground usually subsides whereas at turbine hub altitude it does not decrease that much or may even increase. As a result, the wind speed is higher and a turbine will produce more power than expected from the 1/7 power law: doubling the altitude may increase wind speed by 20% to 60%. A stable atmosphere is caused by radiative cooling of the surface and is common in a temperate climate: it usually occurs when there is a (partly) clear sky at night. When the (high altitude) wind is strong (a 10-meter wind speed higher than approximately 6 to 7 m/s) the stable atmosphere is disrupted because of friction turbulence and the atmosphere turns neutral. A daytime atmosphere is either neutral (no net radiation; usually with strong winds and heavy clouding) or unstable (rising air because of ground heating—by the sun). The 1/7 power law is a good approximation of the wind profile. Indiana was rated as having a wind capacity of 30,000 MW, but by raising the expected turbine height from 50 m to 70 m raised the wind capacity to 40,000 MW, and could be double that at 100 m. For HAWTs, tower heights approximately two to three times the blade length balance material costs of the tower against better utilisation of the more expensive active components.

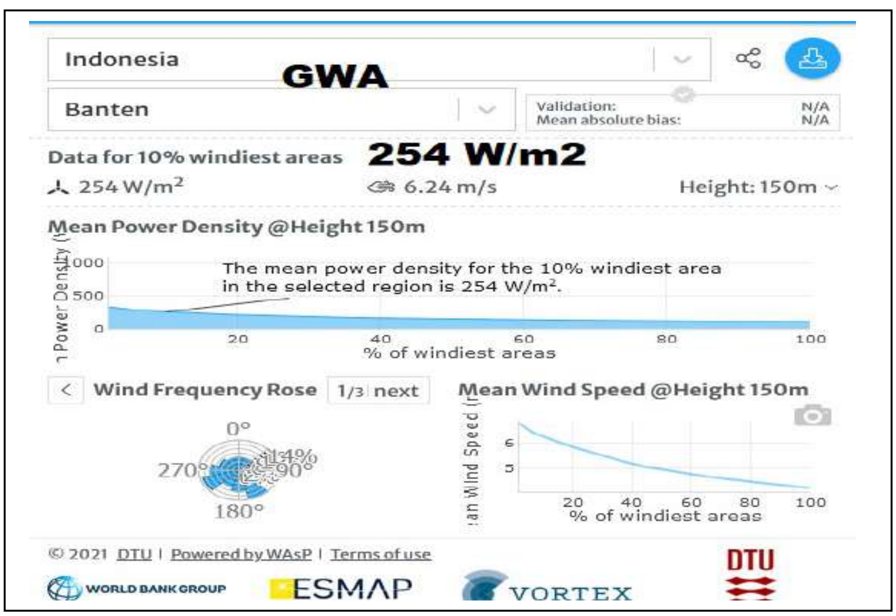
Chapter 3. Reports of Study and power evacuation to PLN grid network

3.1. Banten offshore wind potency

Global Wind Atlas:



Wind Speed 6.24 m/sec :

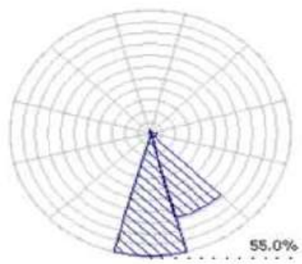


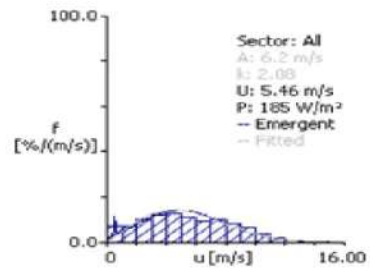
Whypgen Muara Binuangeun coastal Lebak Banten

Wind data Muara Binuangeun, Lebak

height (m)	Actual average wind speed (*m/s*)	Weibull parameter		power density
		c (*m/s*)	k	*W/m²*
10	4.9	5.5	1.97	137
30	5.3	6.0	2.04	171
50	5.5	6.2	2.07	185

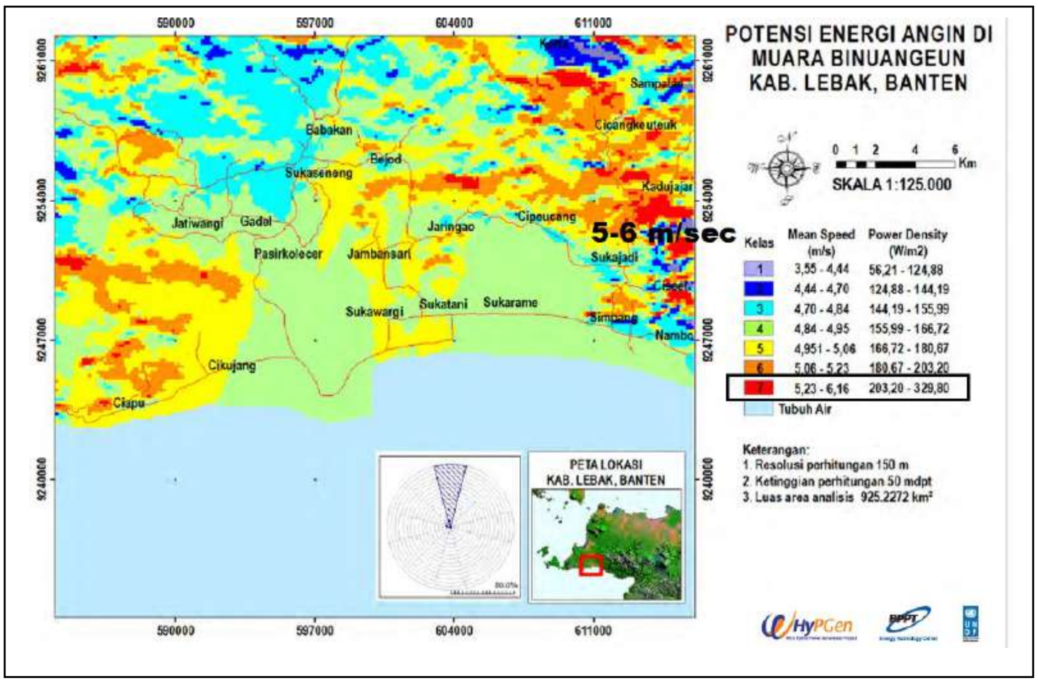
Wind direction and wind speed distribution on 50 m measurement described below



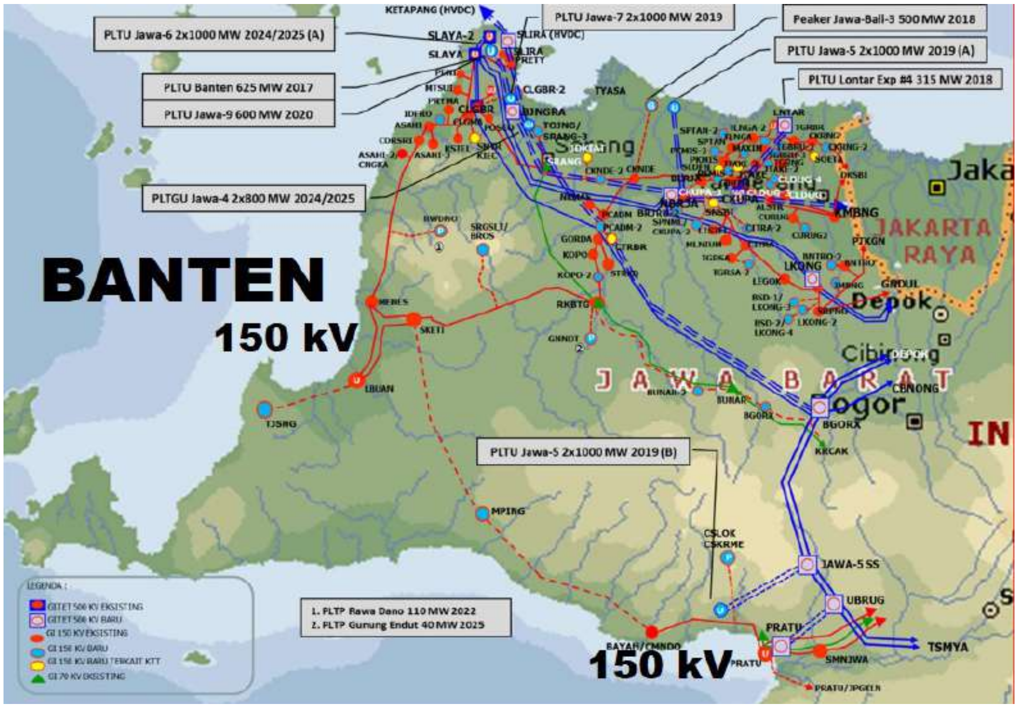


Wind direction is dominated from south (54.6%) and south east (38.9%).

Lebak Onshore Profile :



Power evacuation grid network:



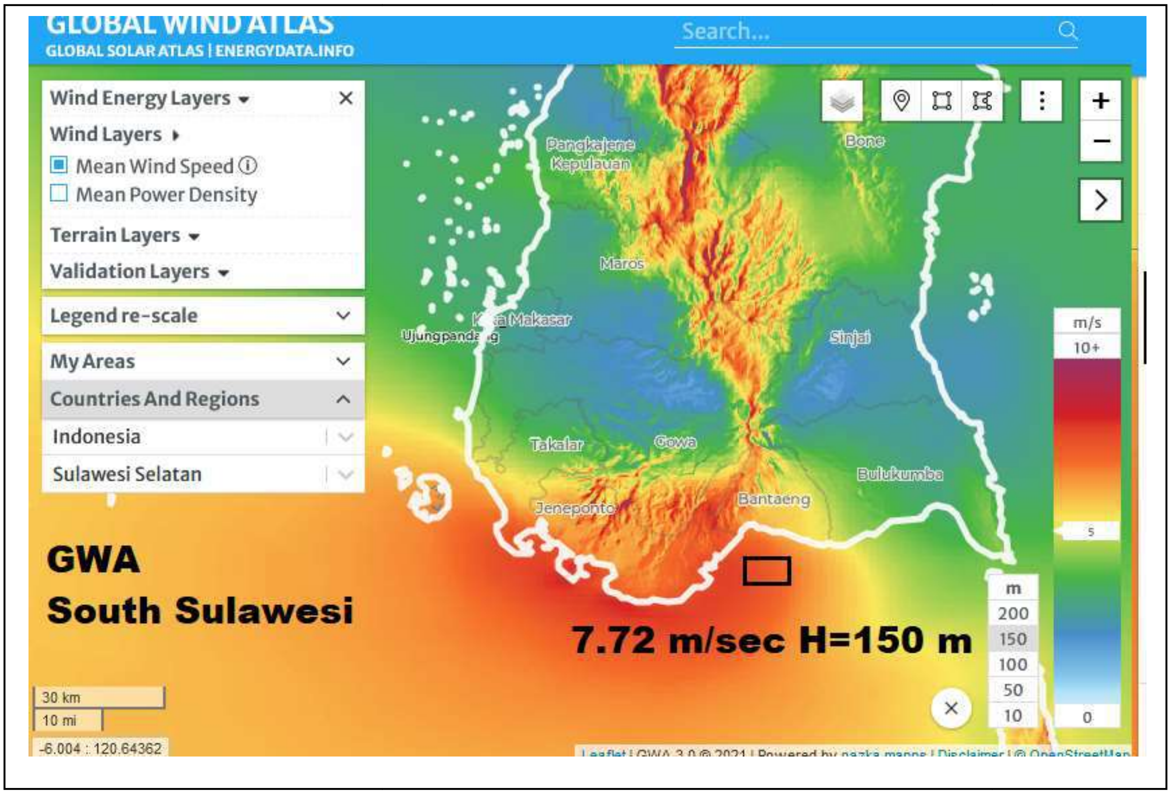
Power Demand :

BANTEN PEAK LOAD = 6000 MW

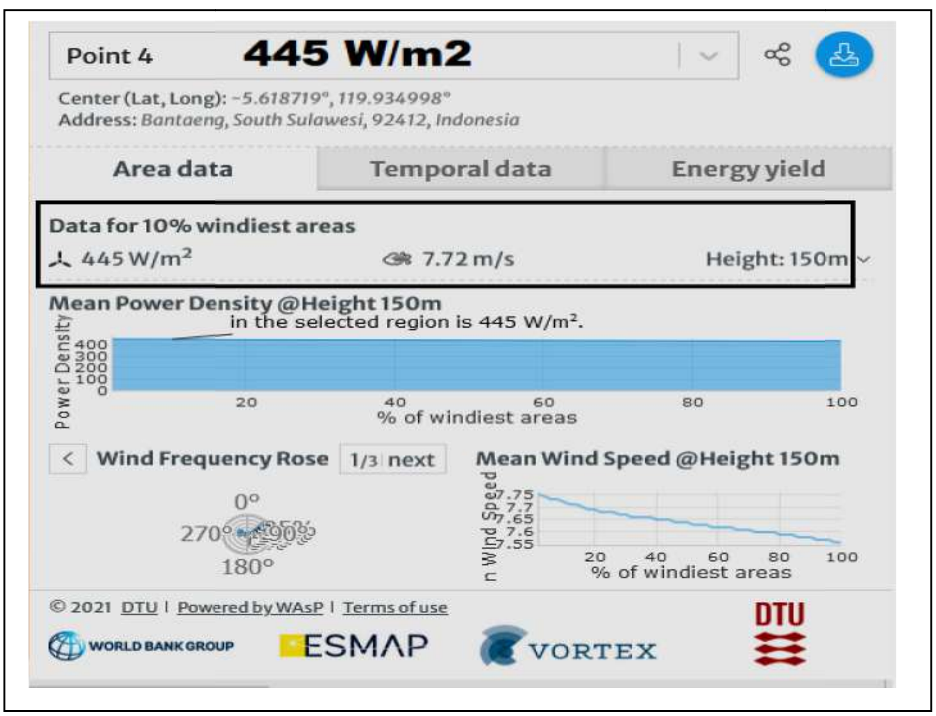
Tahun	Pertumbuhan Ekonomi (%)	Penjualan Energi (GWh)	Produksi Energi (GWh)	Beban Puncak (MW)	Pelanggan
2016	7.19	23,515	25,020	4,035	3,252,725
2017	7.74	26,997	28,707	4,628	3,377,833
2018	8.17	29,477	31,326	5,044	3,500,958
2019	8.72	32,200	34,195	5,497	3,601,244
2020	6.97	35,106	37,254	5,980	3,704,500
2021	6.97	37,639	39,914	6,399	3,805,585
2022	6.97	40,705	43,134	6,904	3,909,125
2023	6.97	43,950	46,551	7,438	4,014,402
2024	6.97	47,528	50,319	8,026	4,122,503
2025	6.97	51,348	54,359	8,656	4,234,021
Pertumbuhan (%)	**7.37**	**9.07**	**9.00**	**8.85**	**2.97**

3.2. South Sulawesi offshore wind potency

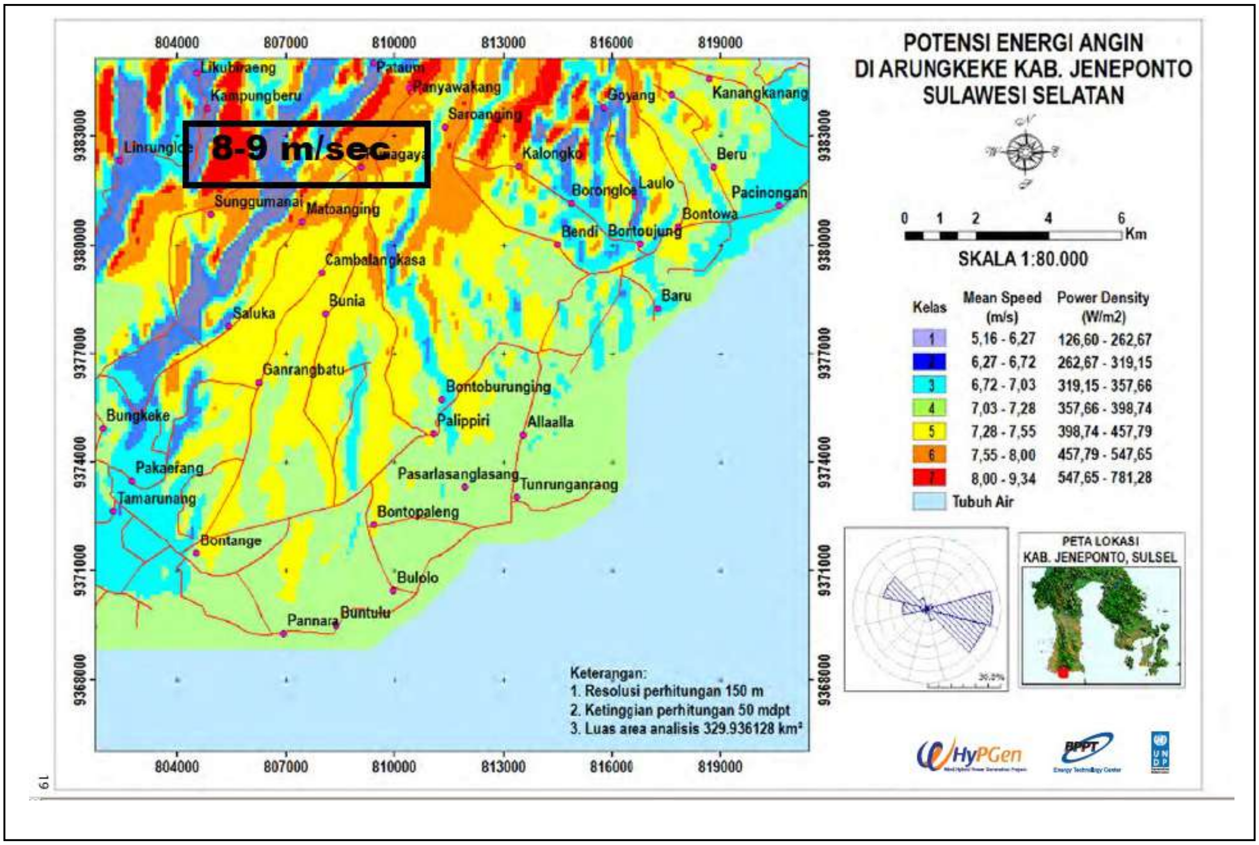
Global Wind Atlas :



Wind speed 7.72 m/sec



Whypgen data:

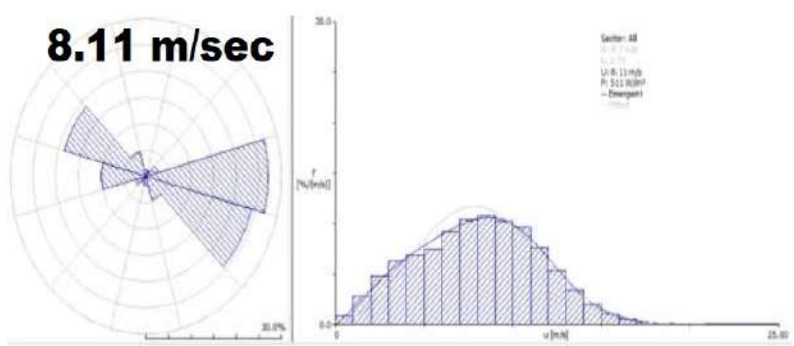


Jeneponto Profile :

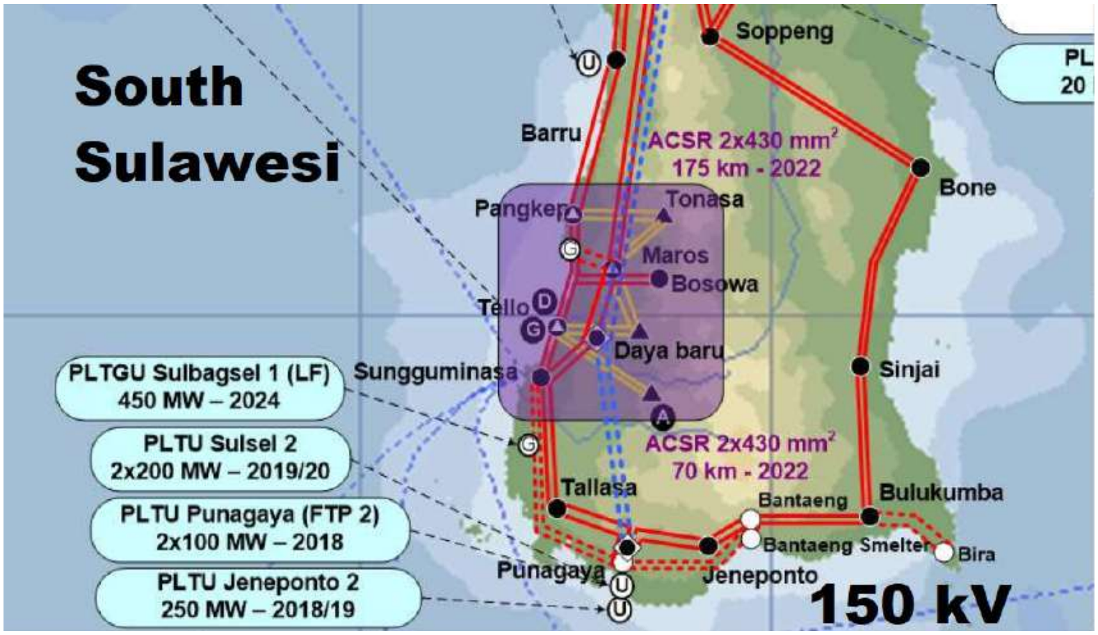
Wind data Jeneponto, South Sulawesi period 2005-2006

height (m)	Mean wind speed actual (m/s)	Weibull parameter c (m/s)	Weibull parameter k	power density W/m^2
50	8.11	9.3	2.73	511

Wind direction and wind speed distribution on 50 m measurement described below



South Sulawesi Grid Network 150 kV:



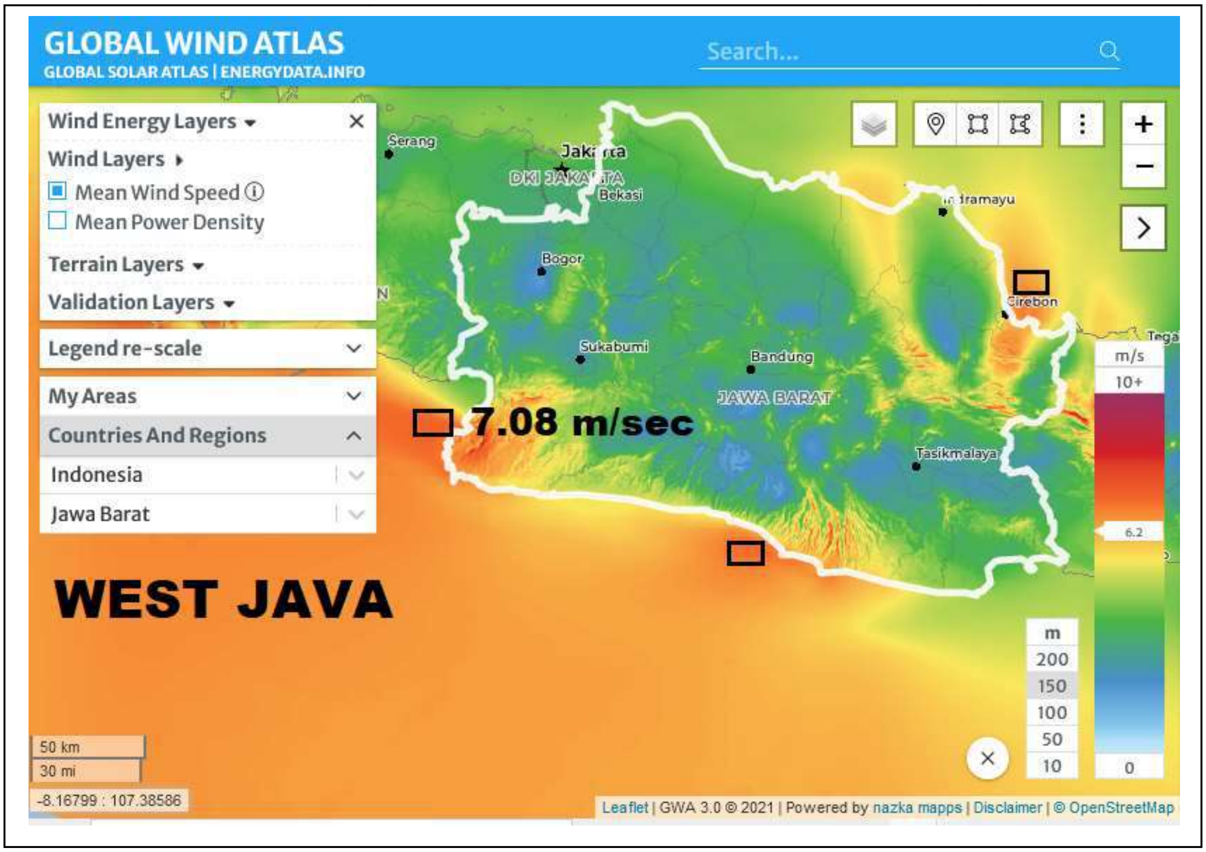
Peak Load Demand:

South Sulawesi Peak Load = 1600 MW

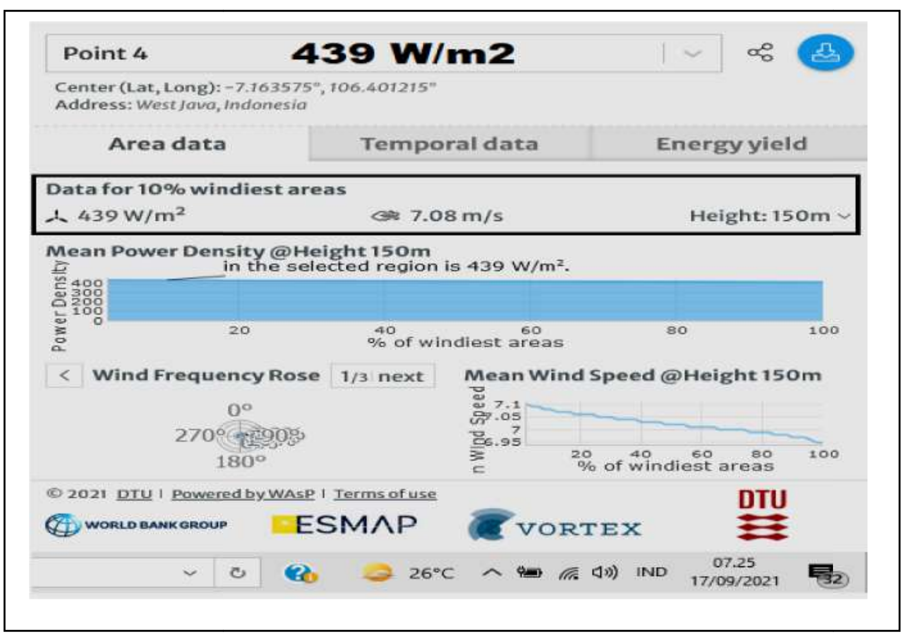
Tahun	Pertumbuhan Ekonomi (%)	Penjualan (GWh)	Produksi (GWh)	Beban Puncak (MW)	Pelanggan
2016	8.9	4,856	5,486	941	1,819,730
2017	9.4	5,830	6,582	1,128	1,857,581
2018	9.7	7,159	8,075	1,383	1,948,596
2019	9.9	7,790	8,779	1,502	2,041,303
2020	9.5	8,740	9,846	1,683	2,135,396
2021	9.5	9,478	10,673	1,822	2,166,906
2022	9.5	10,287	11,580	1,975	2,198,571
2023	9.5	11,174	12,574	2,143	2,230,386
2024	9.5	12,145	13,662	2,326	2,262,400
2025	9.5	13,210	14,858	2,527	2,294,930
Pertumbuhan (%)	9.5	11.9%	11.8%	11.7%	2.6%

3.3. West Java offshore wind potency

Global Wind Atlas:

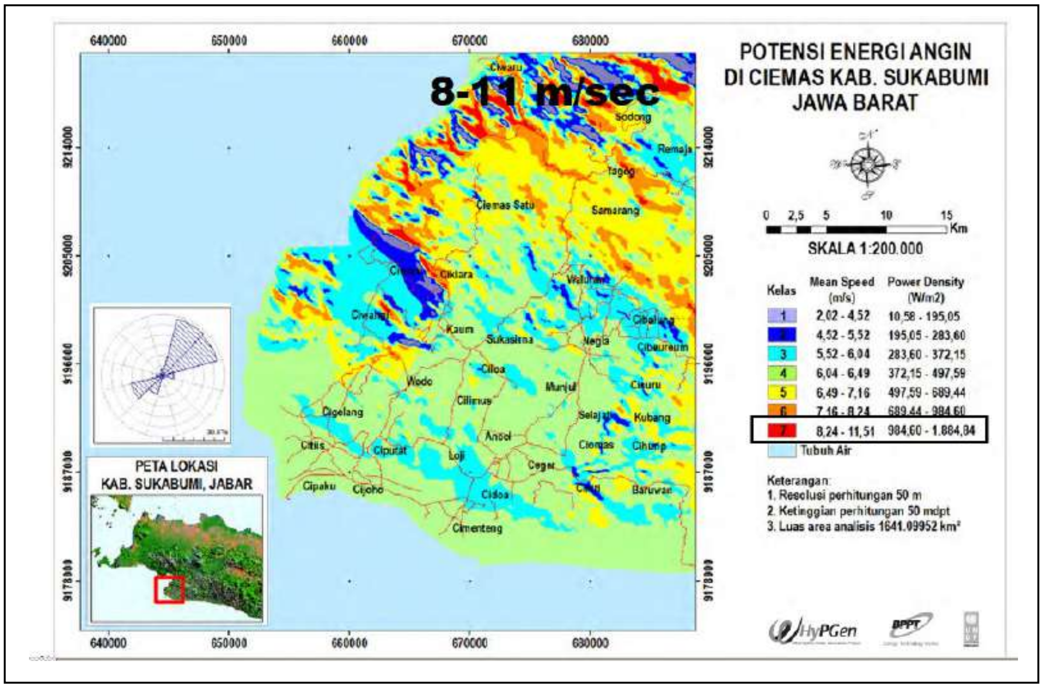


Wind speed = 7.07 m/sec

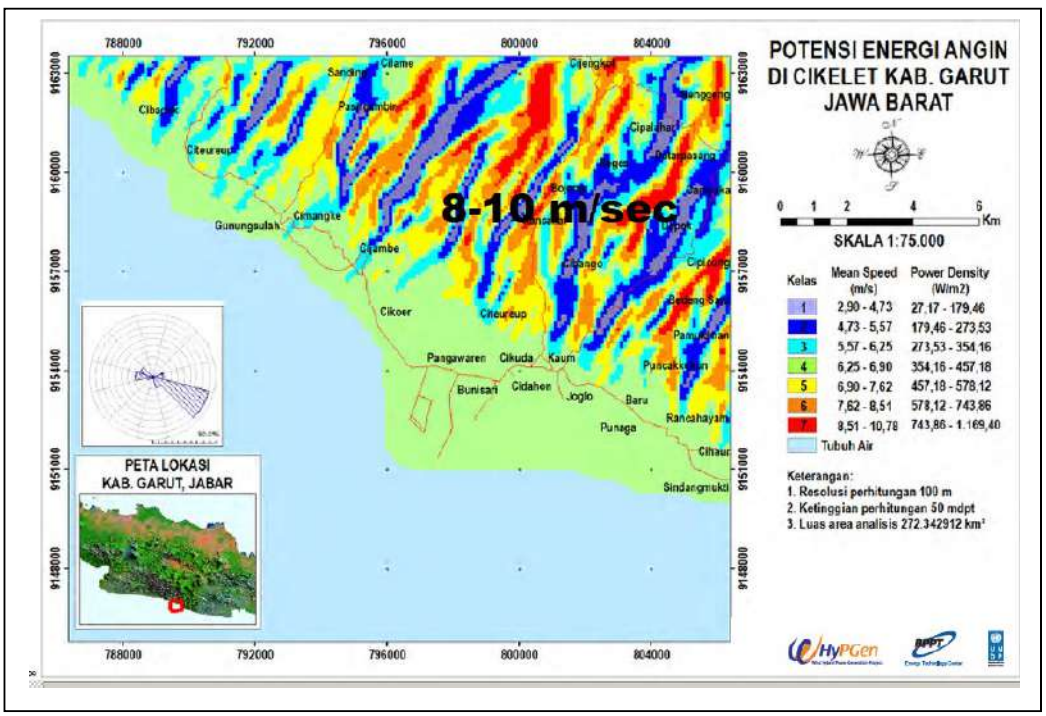


Whypgen data:

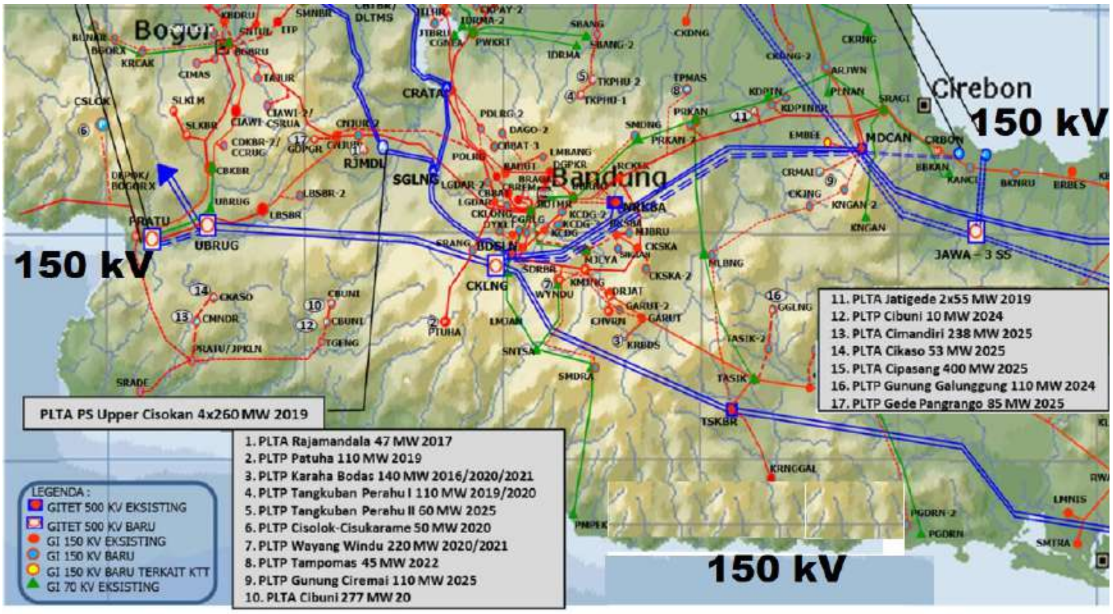
Ciemas Sukabumi



Cikelet Garut



Power evacuation:



Power Demand:

WEST JAVA PEAK LOAD = 11000 MW

Tahun	Pertumbuhan Ekonomi (%)	Penjualan Energi (GWh)	Produksi Energi (Gwh)	Beban Puncak (MW)	Pelanggan
2016	7.19	46,536	50,015	7,755	12,545,304
2017	7.74	50,866	54,603	8,455	13,125,536
2018	8.17	56,213	60,281	9,322	13,742,765
2019	8.72	60,224	64,528	9,965	13,970,876
2020	6.97	63,956	68,477	10,561	14,330,077
2021	6.97	68,504	73,309	11,291	14,562,543
2022	6.97	72,733	77,797	11,966	14,795,958
2023	6.97	77,279	82,618	12,690	15,030,793
2024	6.97	82,239	87,869	13,478	15,267,065
2025	6.97	87,641	93,615	14,340	15,505,147
Pertumbuhan (%)	**7.37**	**7.29**	**7.21**	**7.07**	**2.38**

Chapter 4. Required Feed in Tariff based on BPP tariff of PLN

4.1. BPP PLN tariff 2021

No	BPP PLN 2019-2021	USD Cent/kWh
1	**BPP tariff Banten (USD Cent/kWh)**	**6,91**
2	**BPP tariff West Java (USD Cent/kWh)**	**6,91**
3	**BPP tariff South Sulawesi (USD Cent/kWh)**	**8,25**

4.2. Required competitive EPC Cost and IRR Target

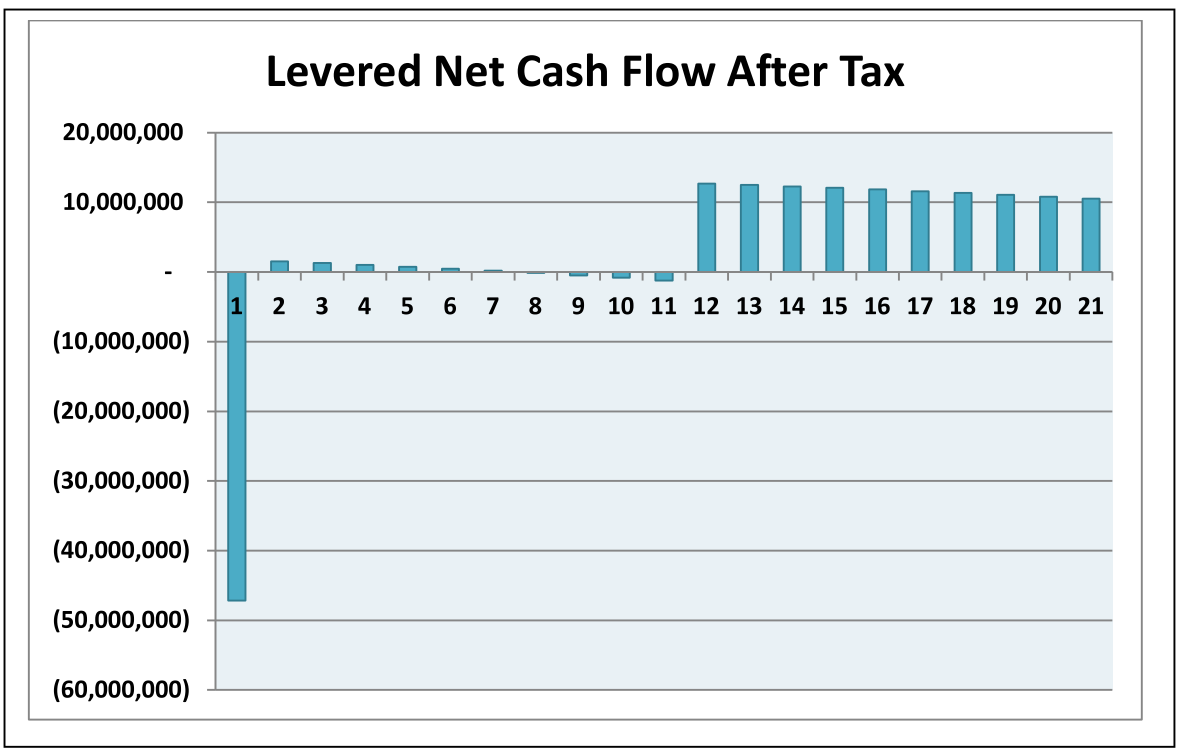
5.2.1. Capacity 100 MW Location Banten offshore (Finmod FIT = USD 6.5 cent/kWh, PLN BPP price = USD 6.91 cent/kWh, Input EPC = USD 1410/kW)

Key inputs :

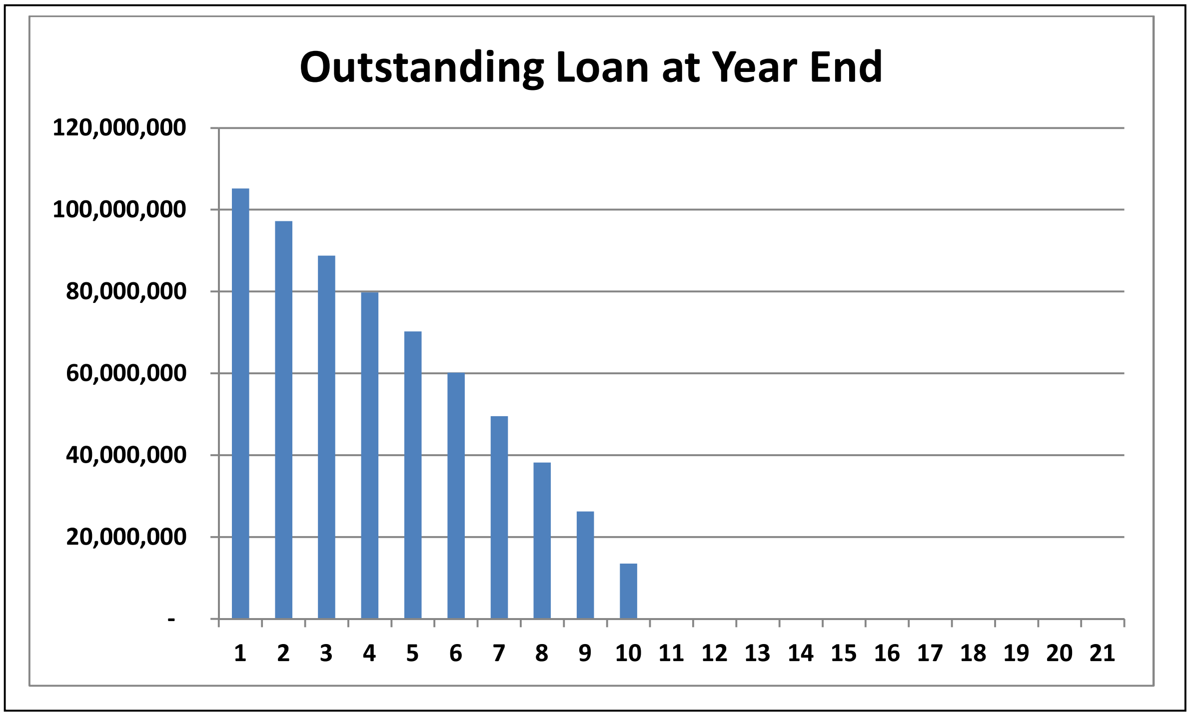
Capacity Offshore Wind	MW	100
Location	Banten	Coastal
Wind Capacity Factor	%	34%
Feed In Tarriff	USD ¢ / kWh	6,50
PPA	year	25
Fixed Interest Rate	%/year	6,0%
Debt-Equity Ratio		70% - 30%
Corporate interest rate	%	25%
Yearly inflation rate	%	3.5%
VAT	%	10%
Loan Tenure	year	15
Maintenance/year	%/year	2,0%
EPC Cost per MW	USD/MW	1.410.650
Capex /MW	USD/MW	1.502.650
Construction period	months	12

Result of simulation :

Project IRR after tax (100 MW offshore wind Banten) =	6,65%



Outstanding loan



4.2.2. Capacity 500 MW Location Banten offshore (Finmod FIT = USD 5.5 cent/kWh, PLN BPP price = USD 6.91 cent/kWh, Input EPC = USD 1200/kW)

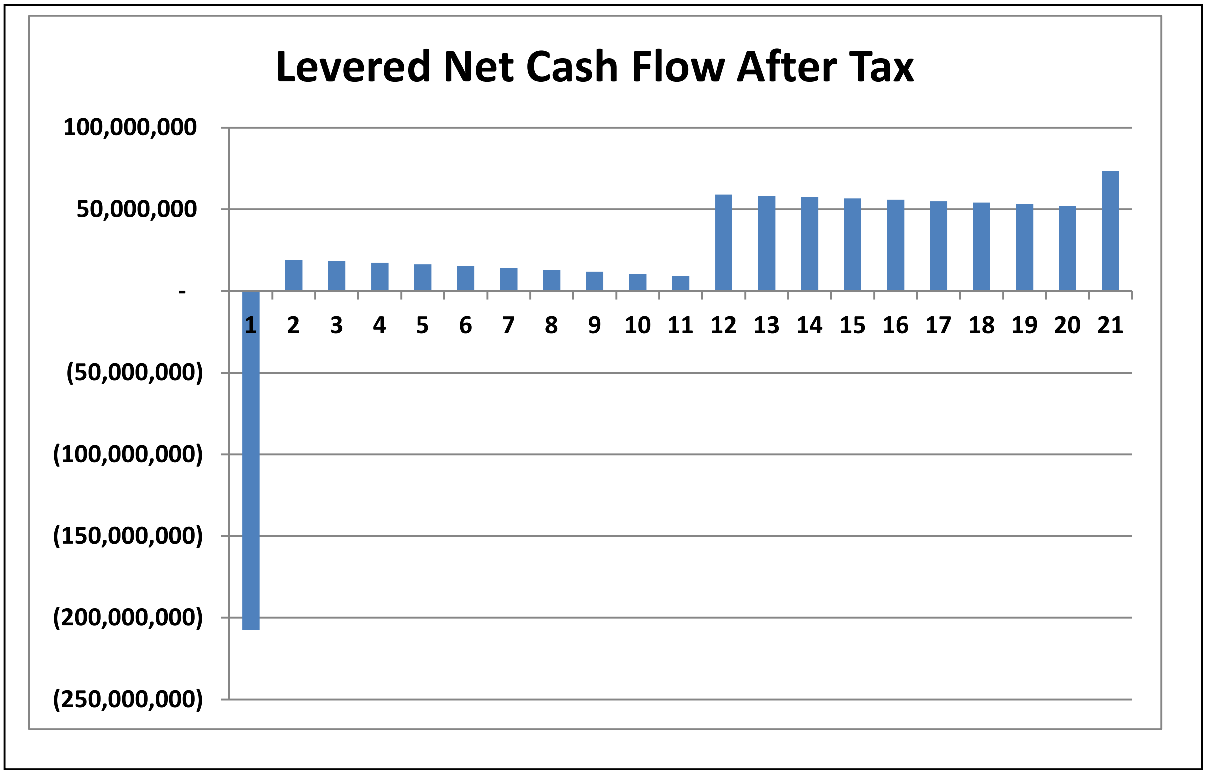
Key Inputs :

Capacity Offshore Wind	MW	500
Location	Banten	Coastal
Wind Capacity Factor	%	37%
Feed In Tarriff	USD ¢ / kWh	5,50
PPA	year	25
Fixed Interest Rate	%/year	6,0%
Debt-Equity Ratio		70% - 30%
Corporate interest rate	%	25%
Yearly inflation rate	%	3.5%
VAT	%	10%
Loan Tenure	year	15
Maintenance	%/year	2,0%
EPC Cost per MW	USD/MW	1.002.130
Capex /MW	USD/MW	1.076.530
Construction period	months	18

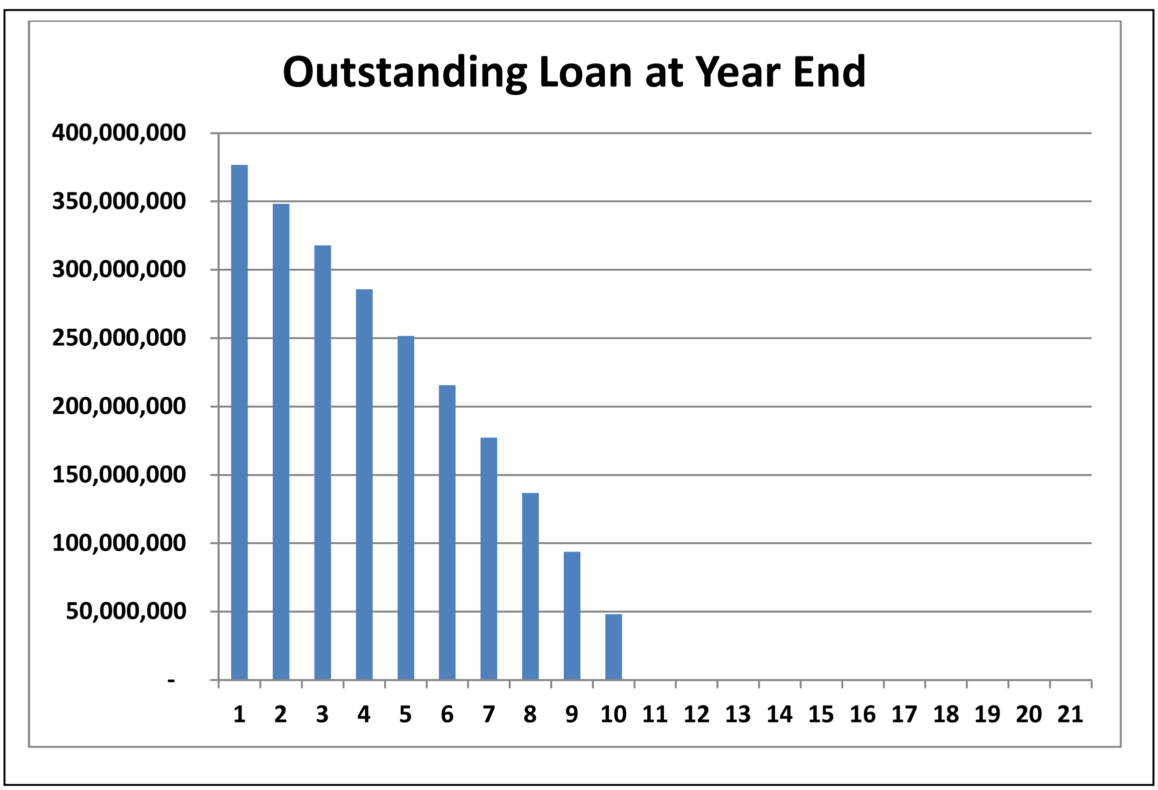
Result of simulation:

Project IRR after tax (500 MW)	11,10%

Project cash flow



Outstanding Loan:



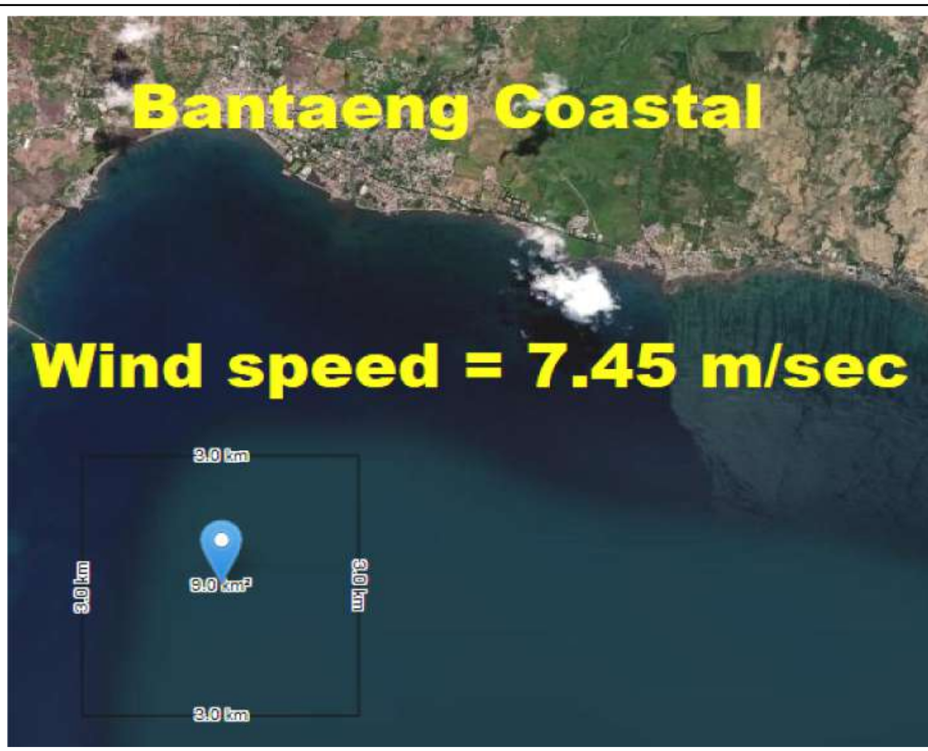
4.2.3. Capacity 500 MW Location South Sulawesi offshore (Finmod FIT = USD 7.5 cent/kWh, PLN BPP price = USD 8.25 cent/kWh, Input EPC = USD 1200/kW)

Key Inputs :

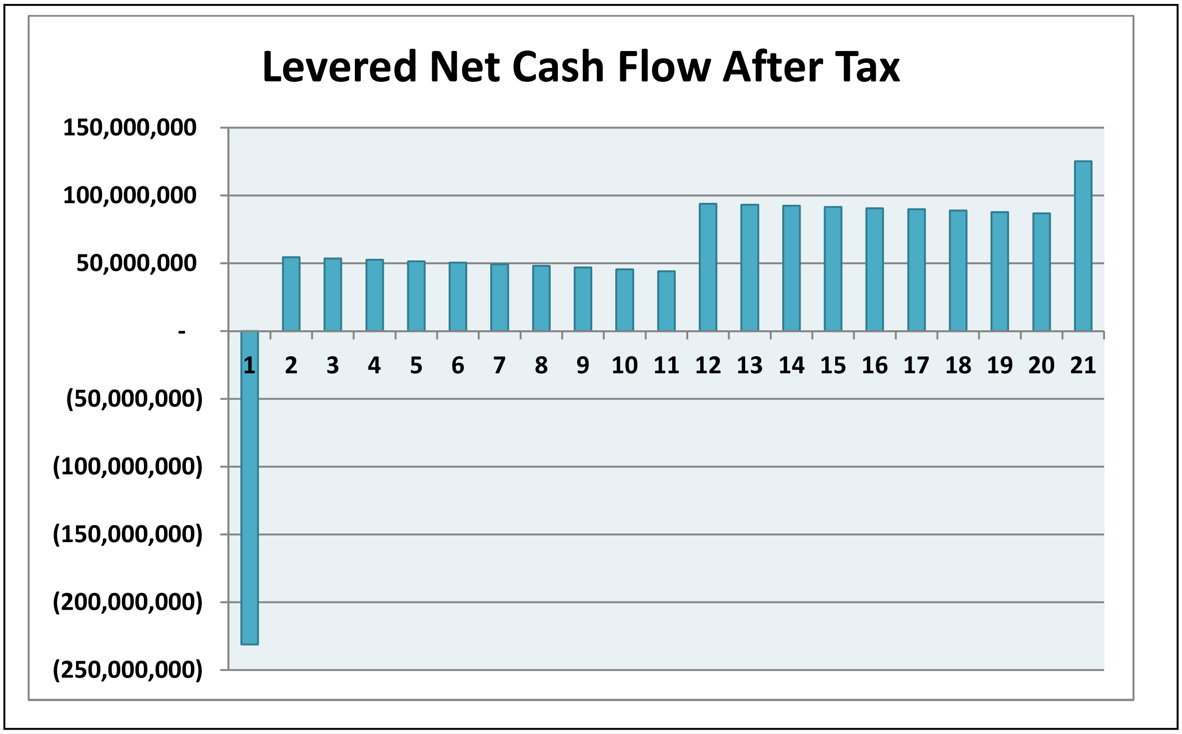
Capacity Offshore Wind	MW	500
Location	South Sulawesi	Coastal
Wind Capacity Factor	%	41%
Feed In Tarriff	USD ¢ / kWh	7,50
PPA	year	25
Fixed Interest Rate	%/year	6,0%
Debt-Equity Ratio		70% - 30%
Corporate interest rate	%	25%
Yearly inflation rate	%	3.5%
VAT	%	10%
Loan Tenure	year	15
Maintenance	%/year	2,0%
EPC Cost per MW	USD/MW	1.002.130
Capex /MW	USD/MW	1.076.530
Construction period	months	18

Result of simulation:

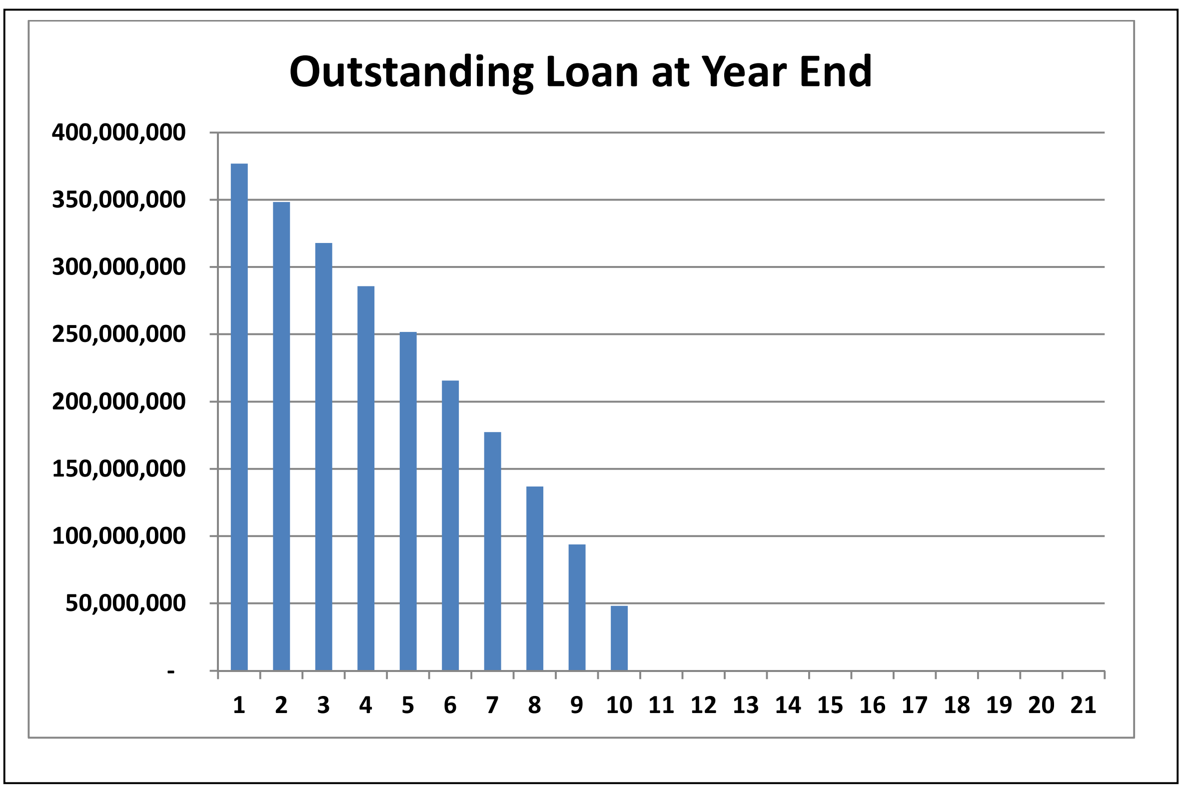
Project IRR after tax (500 MW)	**23,8%**



Project cash flow after tax:



Outstanding Loan



Chapter 5 : Summary

1. In the past 20 years, with the help of technological innovation and scale effect, China's wind turbines price has fallen by 70%, to 3,550 yuan/kW = USD 568/kW; the cost of wind farm construction has dropped by 50%, to 7,160 yuan/kW = USD 1146/kW. The performance and reliability of power generation have been further improved.

2. Indonesia total installed capacity of power generation plant = 83.33 Gigawatt

3. Indonesia total installed capacity of wind turbine = 150 MW

4. Offshore wind potency are Banten, Sukabumi, Cirebon, Banyuwangi, South Sulawesi. These area are supported with nearest backbone of 150 kV PLN network. So it shall be developed with larger capacity to support renewable energy.

5. Required FIT shall be around USD cent 5.5 - 7.5/kWh to fulfil BPP PLN tariff.