Contents

1. PAST STUDIES

In order to understand the wind feasibility of the site, previous studies carried out by M/s. Suzlon Energy Limited, Pune have been taken as reference. The study and findings made by M/s. Suzlon Energy Limited are summarized in this chapter. Under this pre-feasibility study wind farm layout for 700 turbines of S97, 2100 kW model with hub height of 90m along the coast of Gulf of Khambhat was simulated. The prediction assessment has been carried out with two wind monitoring stations namely Vadgam (near khambhat) and Jambusar Nada (near Bharuch) 80m high Suzlon masts. The wind data used for the analysis was measured during the period from Apr-09 to Mar-10 (Vadgam) and during Sep-08 to Aug-09 for Jambusar Nada. The wind speed and wind direction data was measured for every 10-minute interval whereas Temperature & Pressure was measured in hourly interval. The annual mean wind speed recorded at 80m height during Apr-09 to Mar-10 for Vadgam site was **6.0 m/s** with a wind power density of **206 W/m2** at 50m height. With respect to Jambusar Nada, the annual mean wind sped at 80m height during Sep 08 – Aug 09 was measured as **6.5 m/s** with a wind power density of **250 W/m2** at 50m height. Based on the analysis, both sites experience quiet good wind for a comparably higher duration from South of South West (the predominant wind direction). The Figures 1.1 and Figure 1.2 indicates the sites experiencing good wind for a comparable higher duration.

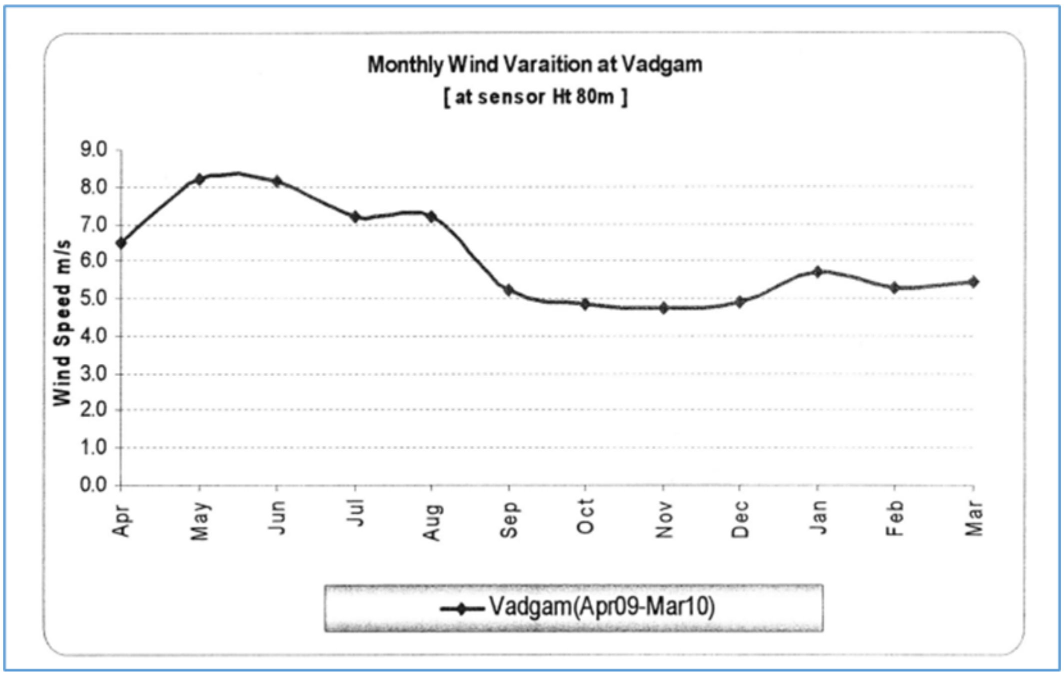


Figure 1.1: Monthly variation of wind speed at Vadgam

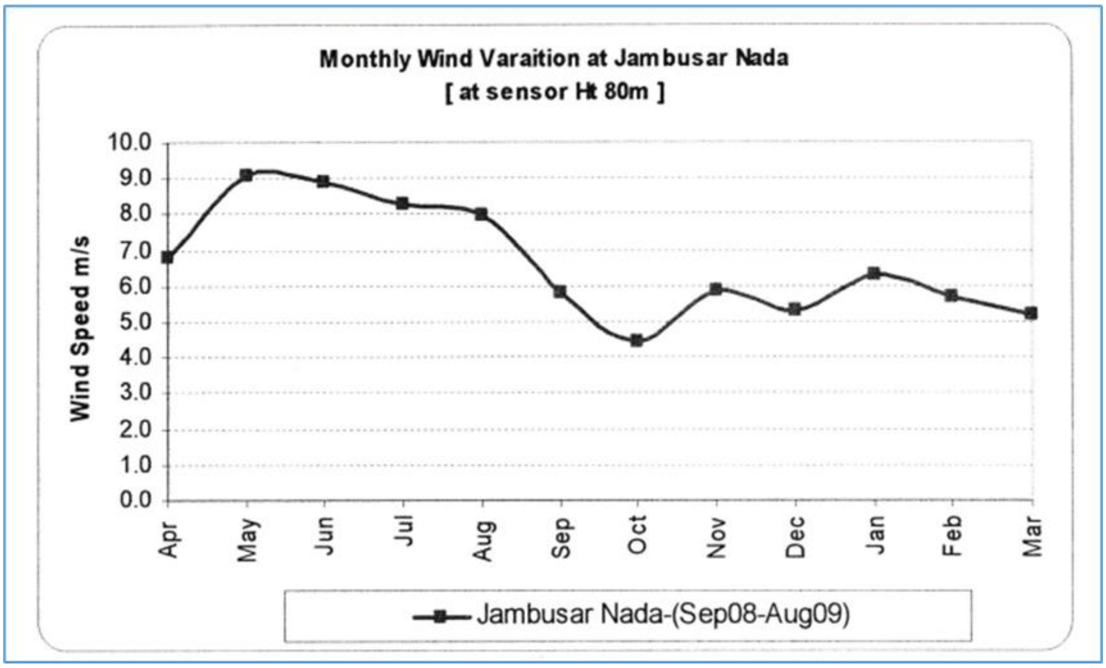


Figure 1.2: Monthly variation of wind speed at Jambusar Nada

The wind farm was micro-sited with the spacing of 9DX13D of S97 (2.1MW) model for 700 machines by considering the wind characteristics and land constraints over the site. The total capacity of the proposed layout design was found to be 1470MW in three windfarm clusters to generate annually 2523 million units of energy.

A Wind-flow modelling simulation was carried out based on WAsP (Wind Atlas Analysis and Application Program) by giving critical inputs of the terrain, roughness, wind data and array positions for calculating annual generation of the windfarm. Moreover, it was observed that over the perimeter of the Wind Turbine Generator there are no buildings or natural obstacles found which could cause significant influence either positive or negative upon the wind flow modelling. It was noted that average site array efficiency for Vadgam was 93.63% and the individual locations array efficiency was in range of +5.17% to -1.73% of the site average. The average estimated annual net energy production per WTG is **39.25 lac units**. And for Jambusar Nada site the average array efficiency was 94.73% and the individual locations array efficiency was in range of +3.05% to -1.49% of the site average. The average estimated annual net energy production per WTG is **47.50 lac units**. Whilst for bankable result the various loss factors were assumed in the production.

In addition to the wind farm, a 1000 MW capacity solar power plant was proposed for implementation in the preliminary analysis towards fulfilling the power requirements of the dam. Based on the preliminary study the site was found to be capable of holding 1000 MW solar farm due to the following reasons;

- Solar insolation in this area is 5.8 kWh/m2 /day.
- 4500 ha land area is proposed to be made available for wind park, of which 3000 ha land area (without any shadow effect) can be available for solar power development.
- Area required for solar PV power is 3.0 hectare/MW, 1000 MW of solar power installation is viable on 3000 ha of land.

Further, the wind and solar power in this region was also found to be complimentary to each other based on the past study.

2. DESIGN BASIS

2.1 Solar Energy

2.1.1 Potential

The solar resource is the single most important parameter to predict the PV Energy output. For any feasibility study, accurate information of solar resource at the location of proposed plant to be developed is very important. Solar energy as received at the surface of earth is classified as Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI) and is measured in the unit kWh/sq.m (Figure 2.1). The solar radiation is continuously variable on a daily basis with seasonal variation throughout the year and regularly intermittent by night fall and irregularly during cloudy and monsoon seasons and influenced by meteorological conditions.

The sunshine hours available at this site has great influence on the solar radiation received at 10m ground level and it decides the amount of power generated. It may be noted that these are site specific and vary significantly depending on the latitude, longitude and elevation. In addition, the atmospheric pollutant like dust is expected to reduce the sunshine intensity impinging on the PV modules depending on the environmental conditions prevailing at the selected site from time to time.

Hence, erroneous data of solar resource may upset the balance sheets of the developer after the commissioning of the plant. Hence, the data source needs to be authentic. In this study, NIWE has used Typical Meteorological Year (TMY) data from the Solar Atlas, developed from its own data of several years from the site at Kalpasar. Based on the solar atlas, the project site identified is very high potential area for the establishment of SPV power plant and the location receives yearly 1758.9 kWh/m2 GHI. The solar Atlas image of the region is shown in Figure 2.2.

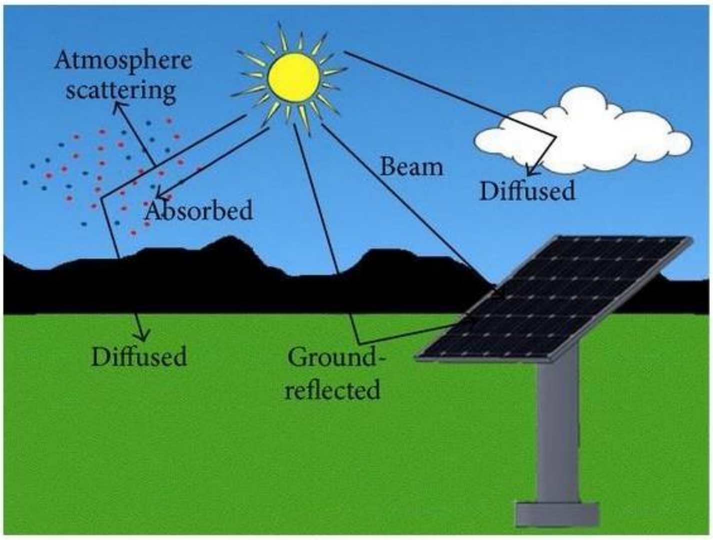


Figure 2.1: Solar radiation DNI, GHI, DHI

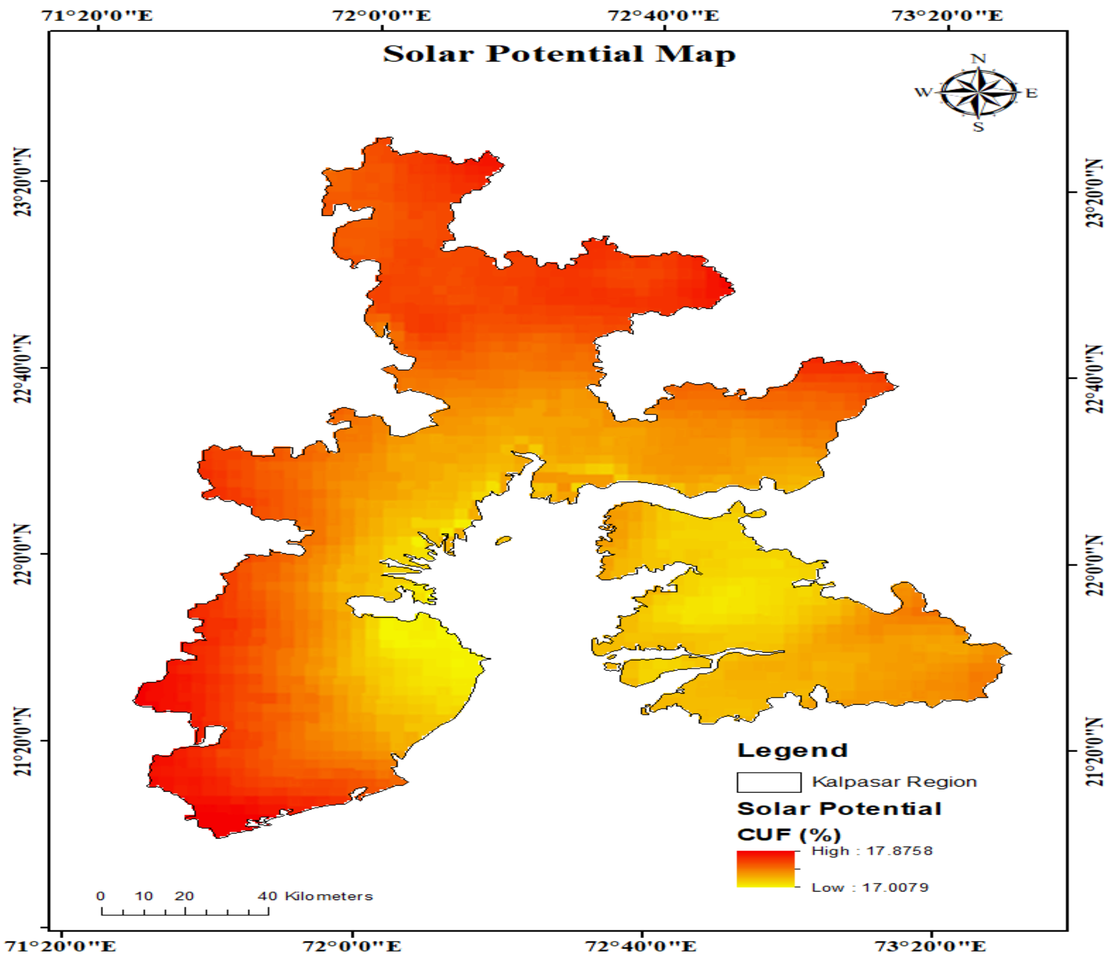


Figure 2.2: Solar radiation DNI, GHI, DHI

2.1.2 Site Specific Requirements

Location & Site Description

The site proposed for the solar feasibility study is situated at the Kalpasar site extends along the Gulf of Khambhat from Bhavnagar to Bharuch district of Gujarat in western part of India. Based on the satellite images, the site is found to be a flat-open terrain, with negligible shadow influence. Considering the same, the solar farm proposed to be developed in this region is expected to have effective solar insolation. The site is located around 90 km in south direction from Ahmedabad city and 85 km to the west of Vadodara city. It is well connected by road network, nearest railway station and Airport is at Vadodara at a distance of 85 km towards east of the site. The site is open and flat; the average elevation of the site varies from 5 m to 12 m amsl.

Site Conditions

Site conditions are essential to be assessed for effective development of wind and solar farms in any proposed site. Since, the Kalpasar wind and solar farm site is expected to be developed in the reclaimed land (due to construction of Dam), the site conditions need to be assessed in a more critical way.

Temperature Conditions

PV modules have a temperature co-efficient that has a negative impact on voltage levels with rise in temperature this means there will be a decrease in power output with a rise in temperature. The annual energy yield of a PV plant is heavily dependent on the actual solar resource of the site and ambient temperature. The increase in temperature has a major impact on the PV module by reducing its voltage, thereby lowering the output power. In addition, increases in temperature are found to be the cause for failure or degradation of PV modules. In the site under study, the month of May is found to be the warmest month of the year 32.80°C and the month of January is found to be the coldest month with average temperature of 20.78°C. The annual average temperature of the site is found to be 27.49°C. The temperature profile is shown in Figure 2.3

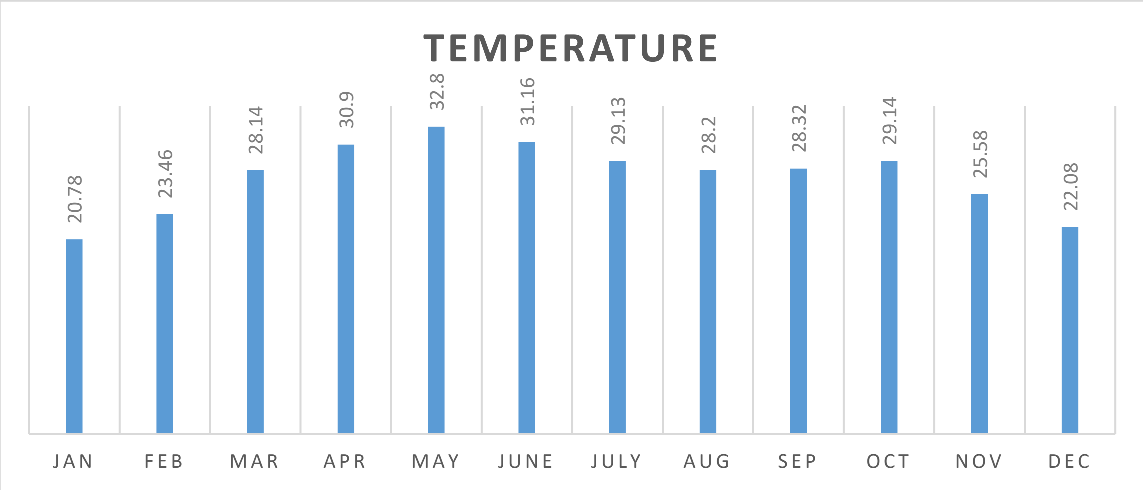


Figure 2.3: Ambient Temperature

Apart from Temperature, other site conditions such as Wind, Turbulence, Seismicity and Soil condition are also expected to be critical for the solar farm development. However, as they are more relevant to wind turbine selection and installation, the same has been covered in the trailing section dedicated to wind power.

2.2 Wind Energy

2.2.1 Potential

Gujarat is the second largest producer of wind power in India with an installed capacity of 9860.62 MW as on 30.11.2022. The state has emerged as a major hub for development of renewable energy in the last few years. The Government of Gujarat had set up the Gujarat Energy Development Agency (GEDA) in 1996 to promote the use of new and renewable energy sources and promote energy conservation activities in the state.

Wind power capacity in Gujarat increased from a meagre 2966 MW in March 2012 to 10400 MW till June 2023. The state of Gujarat is blessed with 1600 Km long coast line and good wind speeds for harnessing the Wind Energy with a supporting topography, hence offers a consistent wind regime highly suited for large capacity windfarms. As per Ministry of New and Renewable Energy sources, Gujarat has a Gross wind potential of 142.56 GW amongst all states at 120m agl. The state is committed to have investment in this segment and to tap the potential of the Wind Energy. Government of Gujarat has announced various incentives schemes in the form of wind Power Policies during year 1993, 2002, 2007 and 2016.

About 50 sites in the state have been declared potential for setting up of windfarms, on the basis of the long term data of Wind speed, collected and analysed under the aegis of the Ministry of New and Renewable Energy and Gujarat Energy Development Agency.

Today, Gujarat ranks 1st amongst all states, with cumulative wind power installation of more than 10400 MW till June 2023, one of Asia's Largest Windfarm of more than 800 MW capacity is situated at dist. Kutch of Gujarat. Various leading State Public Sector units like; GACL, GSFC, GSPC group, GMDC, GPCL, GNFC etc. have also installed windfarms in Gujarat.

Based on the 120m wind atlas (Figure 2.4) prepared by NIWE, the Kalpasar region is having moderate wind potential with %CUF ranging 25-28%.

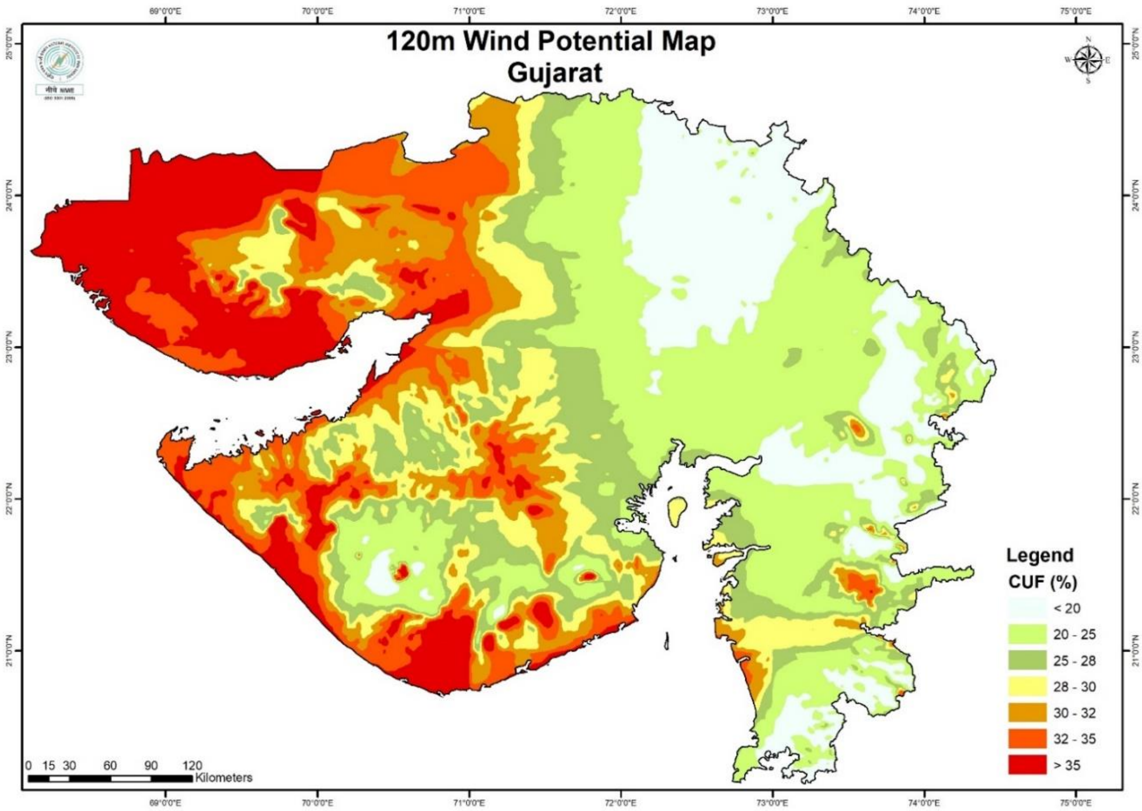


Figure 2.4: 120 m Wind Potential Map of Gujarat

2.2.2 Site-Specific requirements

2.2.2.1. Location & Site Description

The site proposed for the feasibility study is situated at the Kalpasar site extends along the Gulf of Khambhat from Bhavnagar to Bharuch district of Gujarat in western part of India. The site is open and flat and well exposed to prevailing wind. 3 measurements locations data have been considered for this study namely Khavi, Vadgam and Kalpasar to exhibit the wind potential of the site. The region of interest and the mast locations are shown in Figure 2.5 and the mast location details are shown in Table 2.1.

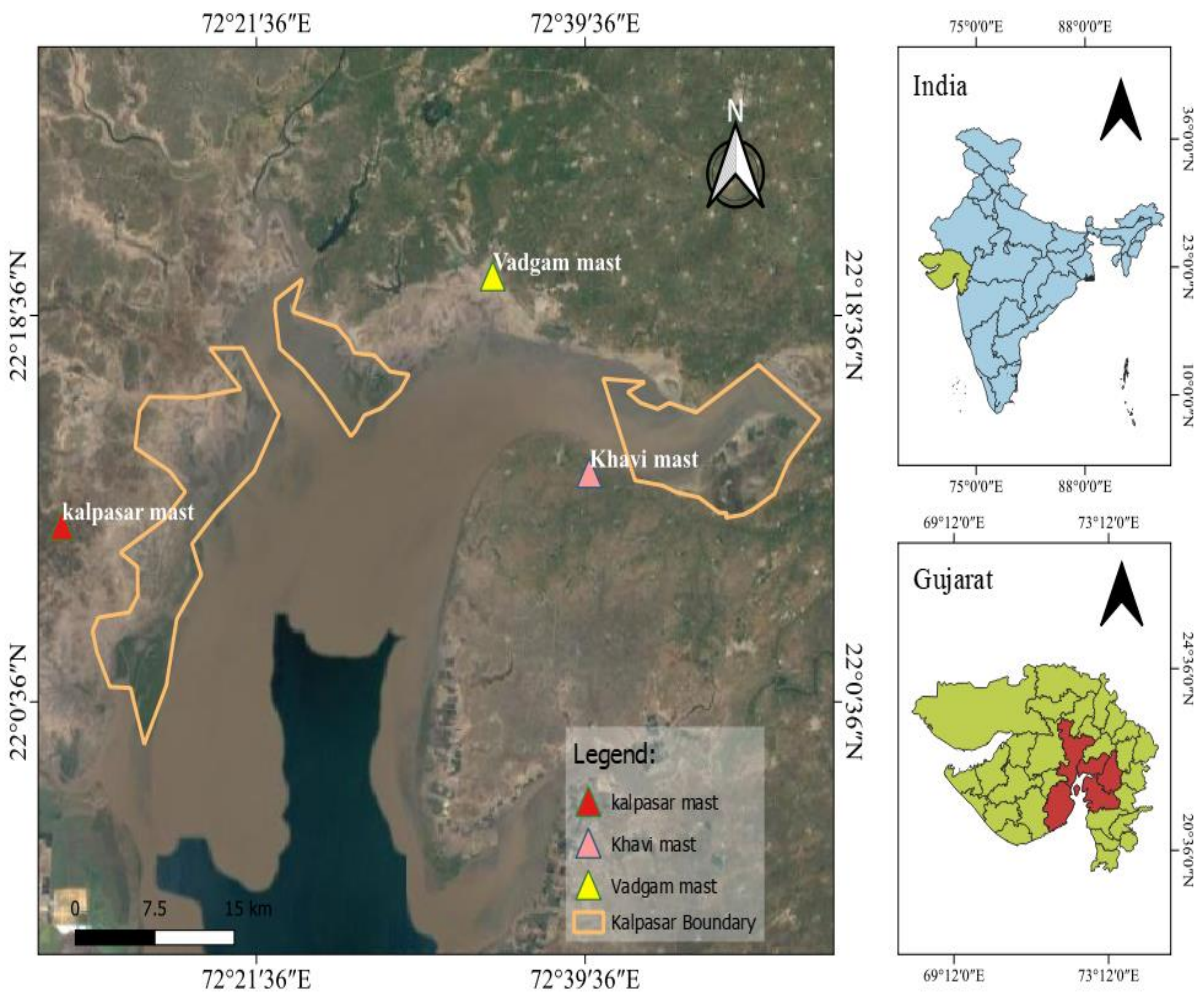


Figure 2.5: The Region of Interest

Table 2.1. Mast Location Details

Mast Name	Latitude °N	Longitude °E	Elev. (m) ASL	Height of Mast (m)	Mean Wind speed m/s	WPD (W/m²)	Turbulence Intensity @15 m/s	Year of data
Khavi	22°11’14.60”	72°39’59.50”	29	100	5.913	204.17	0.099	Jan 2014-Dec 2014
Vadgam	22°20’52.33”	72°23’46.64”	10	50	5.93	200.27	-	Aug 2006-July 2007
Kalpasar	22°8’47.26”	72°10’57.61”	7	100	6.245	237.19	0.077	July 2022 – June 2023

2.2.2.2. Site Conditions:

Wind & Turbulence Conditions:

The maximum vertical load, maximum horizontal load and overturning moment are induced in the wind turbine by wind gusts. The maximum horizontal load and applied overturning moment on the foundation would be substantial compared with the vertical load. Based on the measurements carried out (Khavi, Vadgam & Kalpasar) at the proposed region, the annual average wind speed for the khavi site expected to be in the range of 5.9 at 100m agl & vadgam site expected to be in the range of 5.92 m/s at 50m agl & kalpasar site expected to be in the range of 6.24 m/s at 100m agl. Hence as per the IEC standard 61400-1, Class III type wind turbines are expected to be suitable for the Kalpasar site. The site also seems to exhibit less turbulent wind flow, hence low turbulence class machines are expected to fulfil the requirements at this site.

Seismicity:

Seismically this area is subjected to earthquake of Seismic zone iii i.e. events of moderate magnitude as per the IS: 1893:2000. Hence, the design should be based on the guidelines available for seismic design of wind turbines from Risø Guidelines for Design of Wind Turbines, International Electro-Technical Commission's IEC 61400-1, Wind turbines - Part 1: Design requirements.

Tidal properties:

No impact of tidal waves were noticed in the project site region. However, the gulf of khambhat is having a tidal range varying from 8 to 11m with currents of 2 to 4 m/s which does not create direct impact to proposed turbines. However, the erosion of soil in the shore region in future should be studied. Based on that the type of foundation has to be selected. The tidal properties of the Gulf of Khambhat is shown in the Table 2.2

Table 2.2: Met-ocean Data

TIDES IN THE GULF OF KHAMBHAT	
Highest spring tide	11.0 m
Mean spring tide	8.8 m
Mean tide	6.8 m

Soil Properties:

The soil type in the region of interest are clayey soil with intermediate pockets of silt and sand, shell fragments, sandy silt and a few gravels in the gulf region. Further investigation on carrying out soil properties are:

- Physical properties: Moisture content, unit weight, grain size distribution, porosity, etc.
- Chemical properties: Chloride, Sulphite, pH, Organic matters, Carbonate.

Some of the general test must be carried out with the soil sample collected to select the type of foundations are corrosive test, soil bed strength test, permeability, tri-axial testing and hydrometer testing. Based on that the type of foundation shall be selected.

CRZ Clearance:

Since the site is located at the coast, specific clearances such as CRZ clearance have to be assessed for effective execution of the project.

3. SATELLITE & REANALYSIS DATA

3.1 Solar Irradiation

To identify the project site that having very high potential to establish a Solar PV plant we have used the solar atlas data. The solar resource value from the solar atlas is the single most important parameter to predict the PV Energy output. NIWE has established world's largest network of ground mounted solar radiation monitoring stations across the Nation and created solar database with data available more than 7 years. NIWE has also developed solar atlas of India, which gives solar data for each and every corner of the nation. In this study, NIWE has used Typical Meteorological Year (TMY) data from the Solar Atlas, developed from its own data of several years from the site at Kalpasar.

Table 3.1 shows the Monthly and Annual Global Solar Insolation details for the Kalpasar site. Figure 3.1 shows solar resource availability at Kalpasar location, with monthly average Global Horizontal Irradiance (GHI) in the range of 4.04 – 6.49 kWh/m2/day. The annual mean GHI value observed is 4.8 kWh/m2/day.

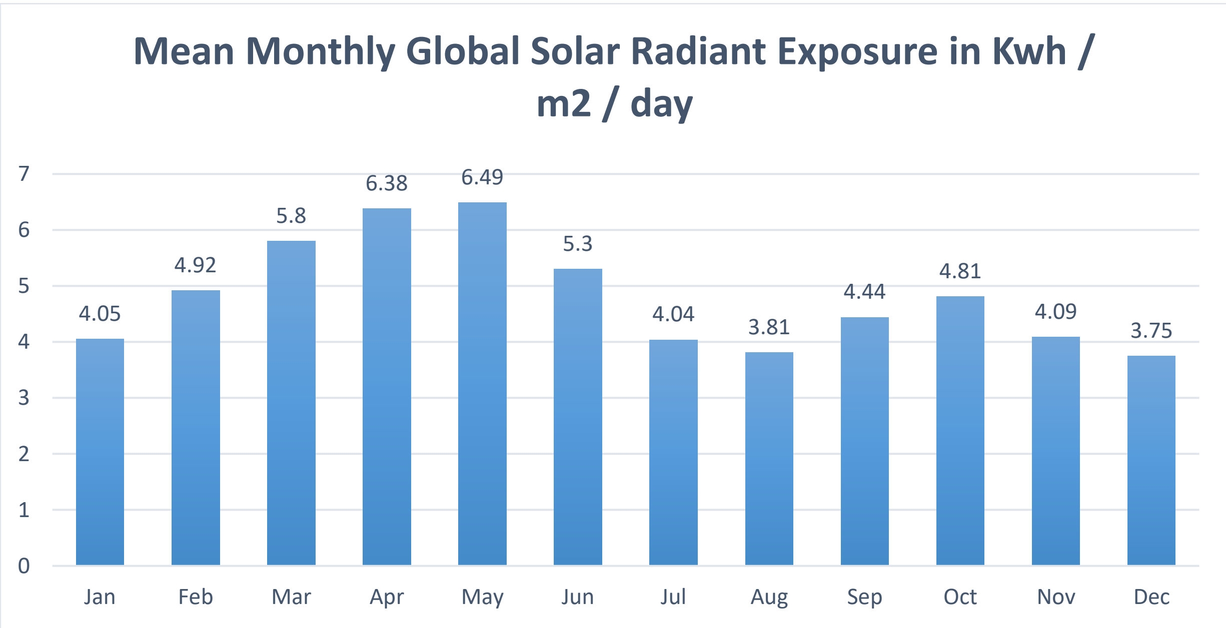


Figure 3.1: Mean Monthly Global Solar Radiant Exposure

Table 3.1: Monthly & Annual Global Solar Insolation at Kalpasar region

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly Global Solar Radiant Exposure in Kwh / m2 / day	4.05	4.92	5.80	6.38	6.49	5.30	4.04	3.81	4.44	4.81	4.09	3.75
No of days	31	28	31	30	31	30	31	31	30	31	30	31
Monthly Global Solar Radiant Exposure in Kwh / m2	125.7	137.8	179.8	191.3	201.3	158.9	125.2	118.0	133.1	149.1	122.6	116.1
Annual	1758.9 kwh/m2											

3.2 Reanalysis Data

In the present analysis, the wind profile for the site is defined by three met. Masts data namely Khavi, Vadgam and Kalpasar wherein minimum one continuous year measurement has been completed. As per the standard wind resource assessment practice, atleast one year measurement has to be correlated with the long-term reference data to represent the long-term variation of the wind characteristics of the site, provided the correlation fits well. For the purpose, ERA5 reanalysis data has been used in the present study to carry out the long-term correction. The long-term correction analysis is detailed in chapter 4.

ERA5 is a climate reanalysis dataset generated through the Copernicus Climate Change Service (C3S) and processed/delivered by ECMRWF (European Center for Medium-Range Weather Forecasting). ERA5 offers hourly predictions of a large number of atmospheric, land, and ocean environment variables. The data cover the Earth on a grid of 30 km and address the atmosphere by using 137 levels from the surface up to 100 km. ERA5 transforms large quantities of historical observations into global estimates using advanced modelling and data assimilation methods. This reanalysis data is helpful in understanding the long-term variability of wind speed in the region of interest. The present section shows the Reanalysis data set used in the study along with its characteristics.

3.2.1 Vadgam Region

In this study, ERA5 grid point located nearby the site (Latitude of 22.250 °N and Longitude of 72.500 °E) has been considered for the period from July 2003 to June 2023 to evaluate the long-term variability. The location of the met mast and the ERA5 points are given in Figure 3.2.The monthly average wind speed at 100m agl obtained from ERA5 data for the period from 2003 to 2023 (20 years) is tabulated in Table 3.2.

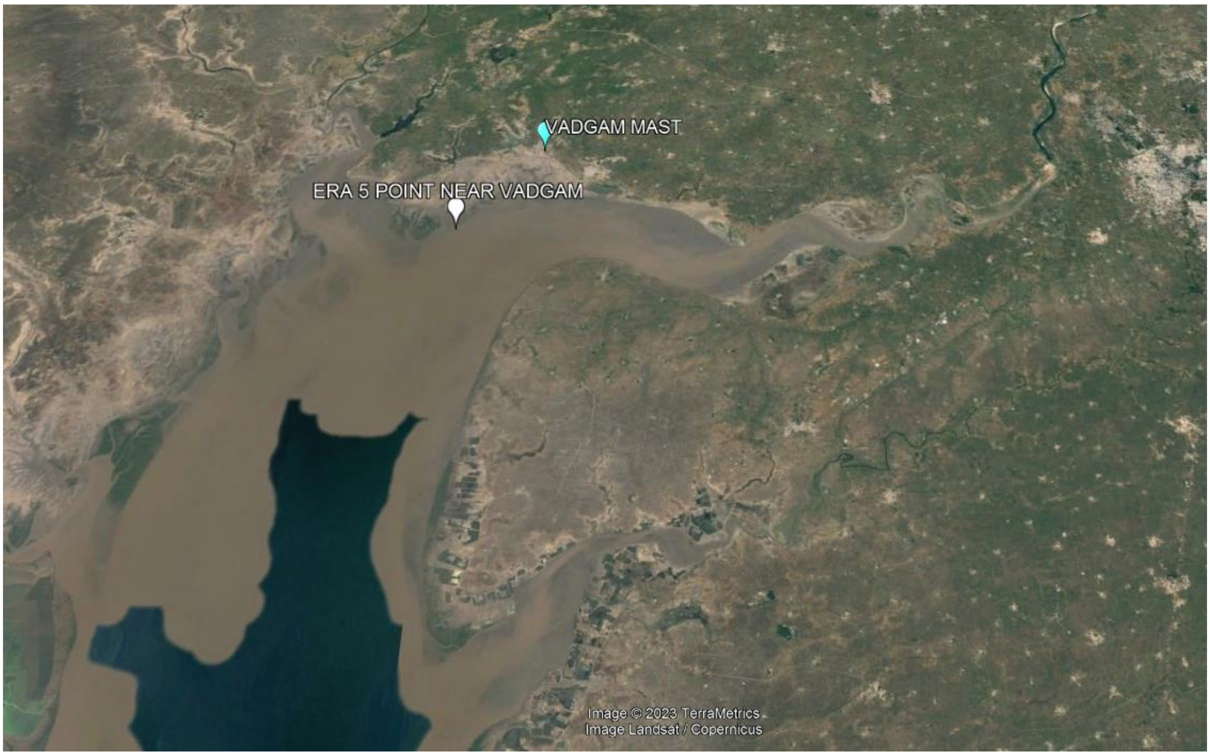


Figure 3.2: ERA-5 Grid points for Vadgam Region

Table 3.2: Monthly average wind speed based on ERA5 near Vadgam mast

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003							6.213	5.78	4.371	3.857	3.714	4.751
2004	4.53	4.115	4.086	5.03	5.95	6.458	6.025	6.205	3.8	4.052	4.079	4.485
2005	5.052	4.296	4.302	4.492	4.689	6.432	6.167	6.165	4.84	3.79	3.925	5.032
2006	4.761	4.073	3.886	4.393	5.688	5.578	7.122	6.723	4.261	3.407	3.826	4.459
2007	5.011	3.739	4.55	4.369	5.976	6.177	6.813	5.796	4.151	3.757	3.446	5.27
2008	5.164	4.944	3.858	4.299	6.539	7.585	6.4	5.44	4.306	3.31	4.5	4.118
2009	4.657	4.034	3.599	4.887	6.616	7.157	6.977	6.02	4.403	4.039	4.173	4.253
2010	4.628	4.168	4.195	4.59	5.698	6.196	5.839	4.907	4.334	3.655	4.115	4.107
2011	4.608	4.132	4.187	4.359	6.128	7.563	5.743	5.503	5.271	3.742	3.786	4.582
2012	4.788	5.117	4.141	4.296	5.39	7.297	6.207	6.132	5.087	3.451	4.187	4.522

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	5.174	4.784	4.268	4.535	5.327	6.002	5.982	5.861	5.108	3.561	4.845	4.692
2014	5.52	4.246	4.498	3.91	4.739	7.801	6.371	5.159	4.177	3.103	3.225	5.397
2015	4.868	4.17	4.22	4.336	4.705	6.613	7.842	5.518	4.847	3.805	3.877	5.036
2016	4.196	4.771	4.214	4.459	5.872	6.234	5.852	5.847	4.827	3.018	4.018	4.521
2017	4.616	4.782	4.373	5.488	5.355	6.572	6.718	5.905	3.541	3.409	4.303	5.413
2018	4.207	4.045	4.213	4.183	5.378	7.188	6.658	6.288	4.823	3.382	3.706	5.224
2019	5.357	4.869	4.622	4.573	5.329	6.425	6.925	6.233	4.499	4.082	3.464	5.467
2020	5.315	5.115	4.791	4.443	4.7	5.614	5.91	6.464	3.341	3.701	4.893	4.536
2021	4.882	3.939	4.117	3.992	5.663	6.071	6.475	5.335	4.726	3.704	5.355	5.224
2022	4.927	3.76	4.585	4.372	5.989	6.218	5.742	5.264	3.768	3.989	4.18	4.925
2023	5.512	3.953	4.225	3.893	4.969	7.593						

By using the data from Table 3.2, the time series of mean monthly variability of wind speed was derived as shown in Figure 3.3. The orange line indicates the average model wind speed of **4.945m/s**, and the grey line indicates 24 months running mean towards understanding the variance of the wind for the time interval of 2 years.

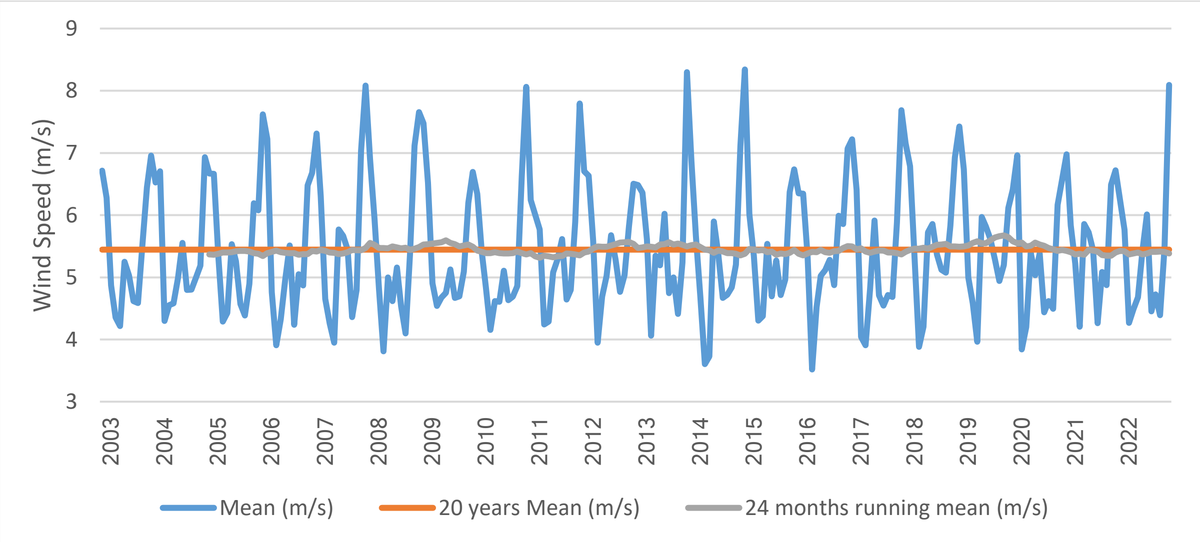


Figure 3.3: Monthly Wind speed time series of ERA-5 data nearby site

3.2.1.1 Inter-Annual variability of wind speed

Similarly using the model data, the time series of annual average wind speed was also worked out for the period of 20 years at 100 m height to understand the inter annual variability. The yearly variations in the wind speeds are depicted in Figure 3.4. It can be seen from the graph that the annual average wind speed values are ranging in between 4.706m/s to 5.160m/s. The orange line denotes the overall long-term average wind speed for 20 years as **4.945m/s**.

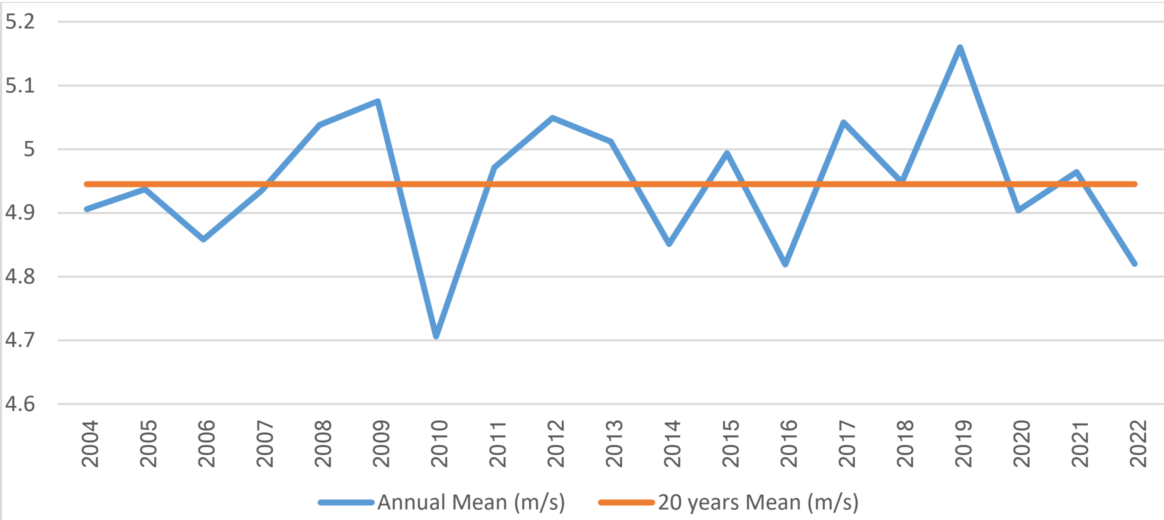


Figure 3.4: Inter-annual variation plot for ERA-5 data nearby site

3.2.2 Khavi Region

ERA5 grid point located nearby the site (Latitude of 22.250 °N and Longitude of 72.750 °E) has been considered for the period from July 2003 to June 2023 to evaluate the long-term variability. The location of the met mast and the ERA5 points are given in Figure 3.5. The monthly average wind speed at 100m agl obtained from ERA5 data for the period from 2003 to 2023 (20 years) is tabulated in Table 3.3.

Figure 3.5: ERA-5 Grid points for Khavi Region

Table 3.3: Monthly average wind speed based on ERA5 near Khavi mast

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003							5.979	5.582	4.195	3.718	3.543	4.48
2004	4.323	3.919	3.912	4.759	5.659	6.102	5.764	5.945	3.468	3.91	3.978	4.386
2005	4.806	4.198	4.048	4.219	4.43	6.009	5.933	5.896	4.496	3.672	3.916	4.871
2006	4.576	4.039	3.728	4.068	5.366	5.353	6.892	6.53	3.939	2.993	3.653	4.214
2007	4.758	3.491	4.482	4.147	5.538	5.797	6.463	5.594	3.939	3.516	3.276	4.922
2008	4.859	4.753	3.585	4.143	6.2	7.227	6.177	5.234	4.019	3.195	4.397	3.889
2009	4.398	3.903	3.52	4.63	6.125	6.635	6.758	5.775	4.093	3.8	3.908	3.983
2010	4.47	4.011	3.959	4.46	5.52	5.847	5.598	4.769	4.195	3.351	3.9	3.871
2011	4.444	4.042	4.076	3.995	5.694	7.107	5.546	5.311	5.035	3.613	3.849	4.353
2012	4.602	4.771	3.997	4.163	5.04	6.883	6.034	5.953	4.915	3.228	4.082	4.284
2013	4.964	4.604	4.15	4.336	5.056	5.661	5.776	5.684	4.785	3.547	4.68	4.482
2014	5.186	3.996	4.236	3.696	4.486	7.402	6.141	4.91	4.043	3.154	3.324	5.091
2015	4.697	3.929	4.098	4.082	4.531	6.057	7.578	5.293	4.459	3.601	3.7	4.785
2016	4.11	4.515	4.078	4.269	5.604	5.984	5.633	5.741	4.401	2.891	3.923	4.418
2017	4.374	4.61	4.202	5.158	5.029	6.168	6.483	5.636	3.441	3.366	4.214	5.178
2018	4.158	3.949	4.029	4.019	4.992	6.834	6.416	6.175	4.555	3.102	3.727	4.984
2019	5.118	4.629	4.35	4.266	4.936	5.941	6.539	6.004	4.258	3.867	3.364	5.087
2020	5.013	4.881	4.478	4.216	4.537	5.254	5.59	6.163	3.181	3.537	4.669	4.333
2021	4.449	3.902	3.849	3.725	5.204	5.763	6.074	5.055	4.454	3.445	5.08	4.906
2022	4.691	3.586	4.408	4.033	5.739	5.747	5.43	5.047	3.484	3.726	4.107	4.655
2023	5.221	3.835	3.991	3.649	4.616	6.993						

By using the data from Table 3.3, the time series of mean monthly variability of wind speed was derived is as shown in Figure 3.6. The orange line indicates the average model wind speed of **4.71 m/s**, and the grey line indicates 24 months running mean towards understanding the variance of the wind for the time interval of 2 years.

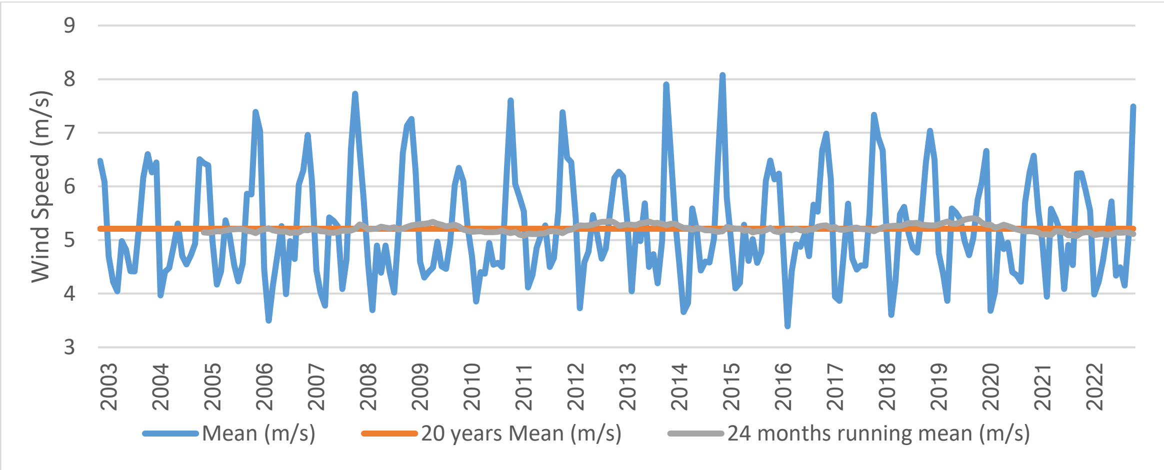


Figure 3.6: Monthly Wind speed time series of ERA-5 data nearby site

3.2.2.1 Inter-Annual variability of wind speed

Similarly using the model data, the time series of annual average wind speed was also worked out for the period of 20 years at 100 m height to understand the inter annual variability. The yearly variations in the wind speeds are depicted in Figure 3.7. It can be seen from the graph that the annual average wind speed values are ranging in between 4.499 m/s to 4.87 m/s. The orange line denotes the overall long-term average wind speed for 20 years as **4.71 m/s**.

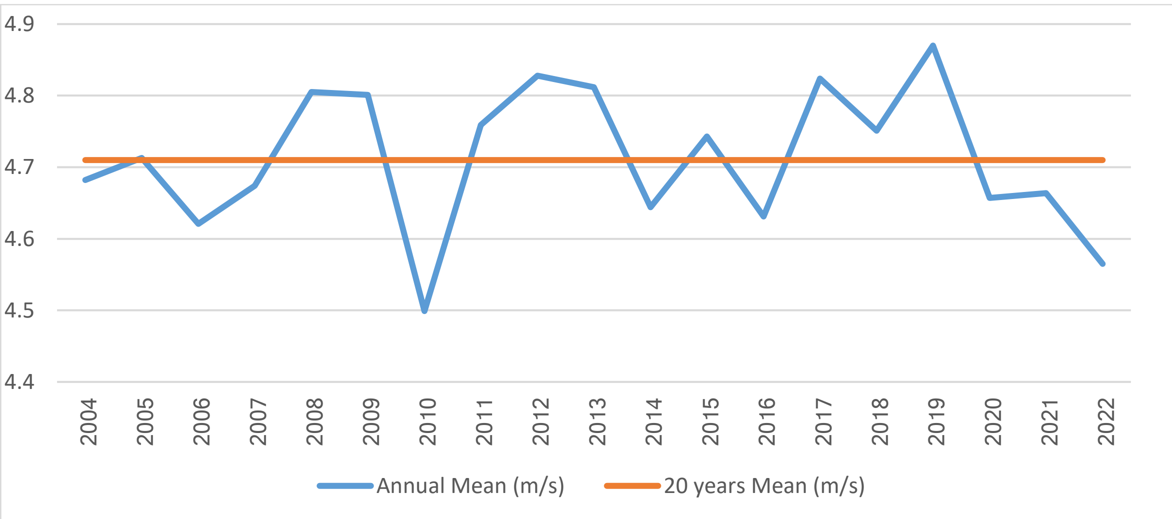


Figure 3.7: Inter-annual variation plot for ERA-5 data nearby site

3.2.3 Kalpasar Region

The monthly average wind speed at 100m agl obtained from nearest ERA5 point (Latitude of 22.250 °N and Longitude of 72.250 °E) for the period from 2003 to 2023 (20 years) is tabulated in Table 3.4. The location of the met mast and the ERA5 points are given in Figure 3.8.

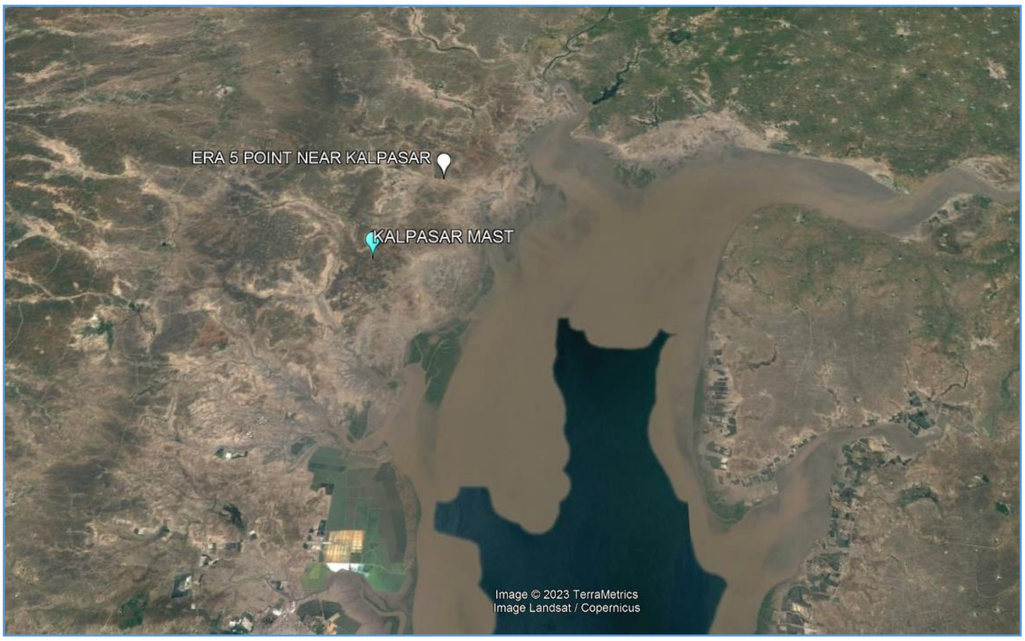


Figure 3.8: ERA-5 Grid points for Kalpasar Region

Table 3.4: Monthly average wind speed based on ERA5 nearby NIWE mast near Kalpasar site

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003							6.331	5.898	4.622	4.055	4.036	5.041
2004	4.755	4.388	4.478	5.104	5.969	6.665	6.179	6.485	4.145	4.148	4.137	4.577
2005	5.372	4.53	4.726	4.69	4.77	6.548	6.385	6.321	5.175	4.036	3.956	5.202
2006	5.013	4.26	4.277	4.66	5.697	5.667	7.371	6.968	4.519	3.787	4.081	4.753
2007	5.294	4.041	4.697	4.758	6.075	6.292	7.019	5.936	4.424	4.105	3.678	5.563
2008	5.544	5.184	4.273	4.592	6.455	7.671	6.573	5.67	4.556	3.586	4.698	4.432
2009	4.996	4.415	3.951	5.241	6.573	7.158	7.094	6.145	4.636	4.369	4.322	4.543
2010	4.855	4.503	4.501	4.656	5.751	6.209	5.983	5.015	4.486	4.066	4.364	4.429
2011	4.894	4.367	4.535	4.953	6.185	7.856	5.833	5.649	5.401	3.875	3.813	4.842
2012	5.067	5.529	4.474	4.522	5.423	7.339	6.383	6.257	5.239	3.729	4.368	4.75
2013	5.402	5.026	4.534	4.901	5.321	6.162	6.161	5.993	5.499	3.666	4.98	4.942

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	5.779	4.581	4.779	4.215	4.875	7.769	6.493	5.4	4.323	3.249	3.28	5.636
2015	5.052	4.531	4.403	4.533	4.691	6.884	8.013	5.628	5.161	4.015	4.141	5.27
2016	4.403	5.041	4.535	4.784	5.801	6.279	6.046	5.975	5.256	3.306	4.203	4.685
2017	4.956	5.029	4.801	5.704	5.512	6.693	6.996	6.149	3.753	3.728	4.421	5.547
2018	4.354	4.309	4.594	4.576	5.548	7.189	6.789	6.386	4.991	3.667	3.796	5.422
2019	5.559	5.263	5.073	4.957	5.511	6.652	7.164	6.382	4.713	4.298	3.664	5.796
2020	5.64	5.319	5.047	4.891	4.999	5.726	6.027	6.671	3.535	4.008	5.089	4.735
2021	5.353	4.174	4.471	4.288	5.926	6.144	6.826	5.574	4.893	3.99	5.568	5.467
2022	5.118	4.089	4.918	4.702	5.978	6.327	5.956	5.445	4.058	4.271	4.238	5.193
2023	5.827	4.13	4.365	4.296	5.17	7.881						

By using the data from Table 3.4, the time series of mean monthly variability of wind speed was derived as shown in Figure 3.9. The orange line indicates the average model wind speed of **5.164m/s**, and the grey line indicates 24 months running mean towards understanding the variance of the wind for the time interval of 2 years.

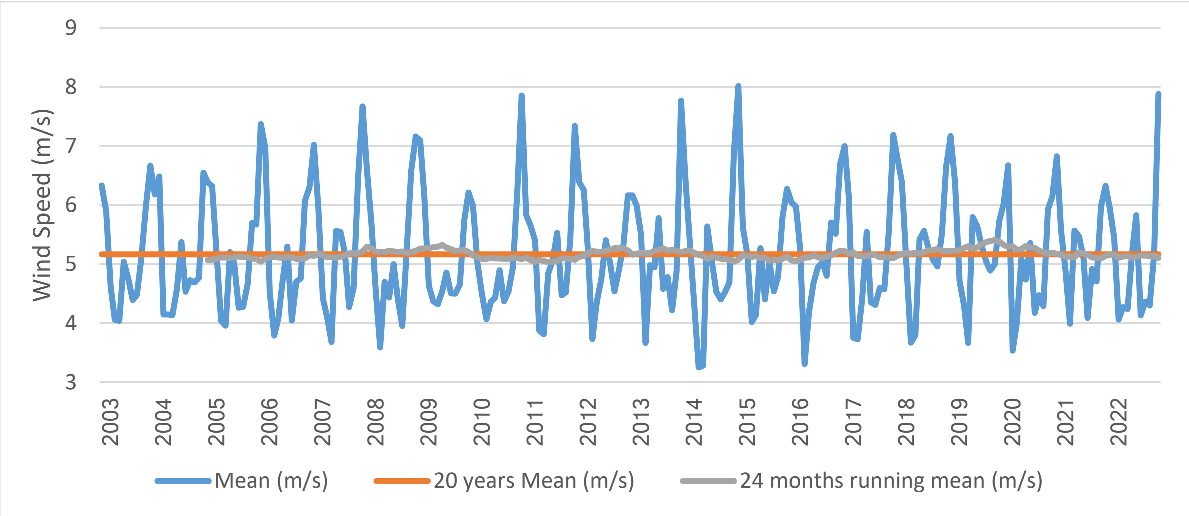


Figure 3.9: Monthly Wind speed time series of ERA-5 data nearby site

3.2.3.1 Inter-Annual variability of wind speed

Similarly using the model data, the time series of annual average wind speed was also worked out for the period of 20 years at 100 m height to understand the inter annual variability. The yearly variations in the wind speeds are depicted in Figure 3.10. It can be seen from the graph that the annual average wind speed values are ranging in between **4.905m/s** to **5.425m/s**. The orange line denotes the overall long-term average wind speed for 20 years as **5.164m/s**.

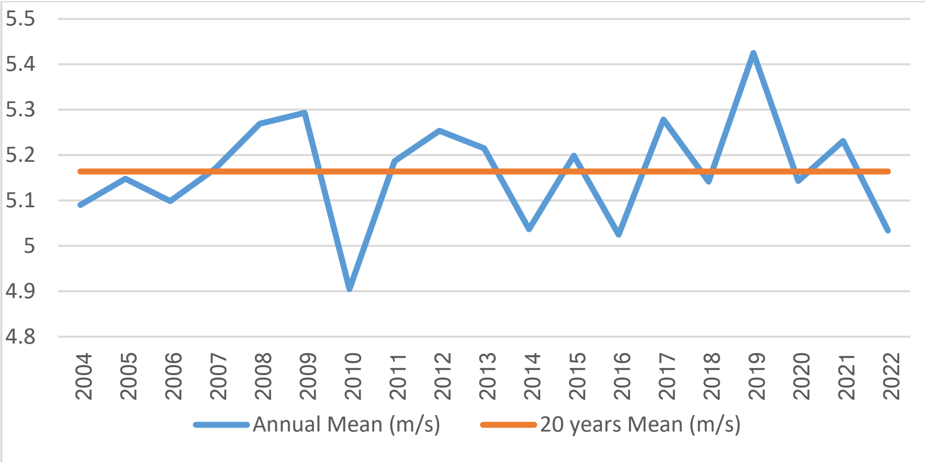


Figure 3.10: Inter-annual variation plot for ERA-5 data nearby site

4. WIND PROFILE

4.1 Past Studies

In the present analysis, the wind profile for the site is defined by three met. Masts data namely Khavi, Vadgam and Kalpasar wherein minimum one continuous year measurement has been completed. In this analysis in the one year data which was not available during the previous studies is made available with in this analysis.The wind profile details of the three measurements are detailed below;

4.1.1 Vadgam Region

The Month wise wind characteristics of Vadgam site is shown below in Table 4.1.

Table 4.1: Month-wise Wind characteristics for Vadgam

Months	50m (m/s)	30m (m/s)	10m (m/s)
Aug	6.889	6.521	6.018
Sep	4.751	4.464	4.124
Oct	4.298	3.866	3.069
Nov	4.714	4.221	2.991
Dec	5.221	4.400	3.220
Jan	5.382	4.546	3.329
Feb	5.741	4.935	3.625

Mar	5.610	4.986	3.925
Apr	5.912	5.336	4.421
May	7.524	7.166	6.386
Jun	7.211	6.883	6.206
Jul	7.852	7.527	6.875
Average	**5.925**	**5.405**	**4.518**

Based on the wind directional data it was seen that the predominant wind direction of the Vadgam site is South West and the secondary wind direction is from North East. The wind rose diagram is shown below in Figure 4.1.

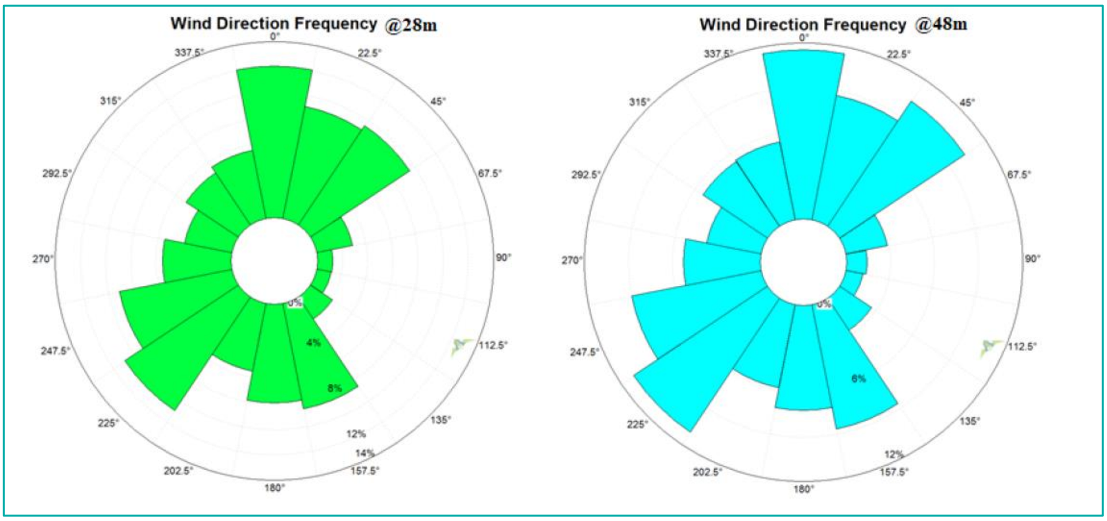


Figure 4.1: Wind Rose (August 2006 to July 2007)

The site air density calculated at the station was based on the measured Temperature, Pressure & Humidity data. The month-wise details of the environmental parameters are shown below in Table 4.2. Table 4.3 & 4.4 detail the Month-Wise Wind Power density and overall summary details at Vadgam site respectively.

Table 4.2: Month-wise Environmental Parameter details

Month	Air Density (kg/m^3)
Aug	1.219
Sep	1.219
Oct	1.219

Month	Air Density (kg/m^3)
Nov	1.219
Dec	1.219
Jan	1.214
Feb	1.209
Mar	1.212
Apr	1.219
May	1.219
Jun	1.219
Jul	1.219
Average	**1.217**

Table 4.3: Month-wise Wind Power Density

Month	50m (W/m^2)	30m (W/m^2)	10m (W/m^2)
Aug - 2006	246.52	212.80	165.58
Sep - 2006	102.02	86.57	66.65
Oct - 2006	87.54	62.50	35.15
Nov - 2006	93.50	63.99	23.30
Dec - 2006	130.47	72.93	28.23
Jan - 2007	131.13	77.44	33.13
Feb - 2007	151.70	95.61	41.23
Mar - 2007	159.84	109.93	55.43
Apr - 2007	192.76	144.43	87.19
May - 2007	398.58	348.76	254.37
Jun - 2007	343.77	300.22	222.54
Jul - 2007	362.89	319.22	243.19
All	**200.27**	**158.10**	**104.91**

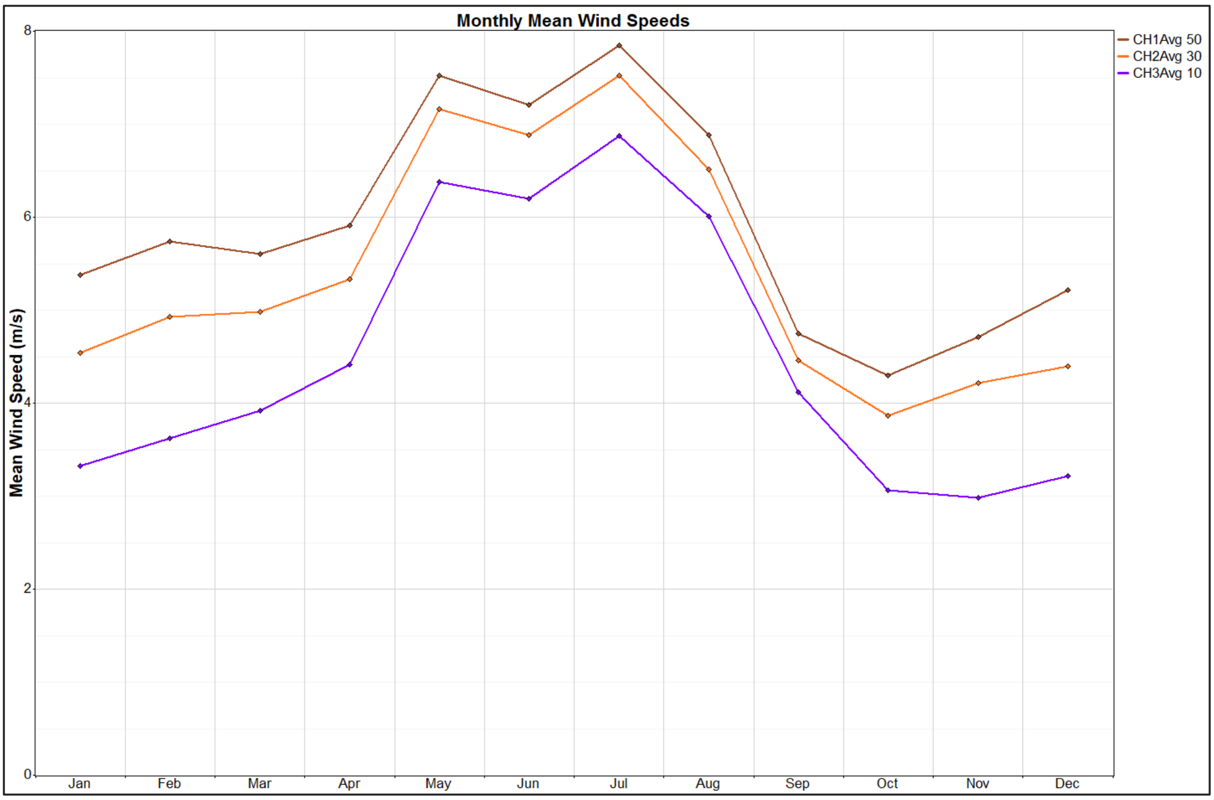


Figure 4.2: Monthly Mean Wind Speed

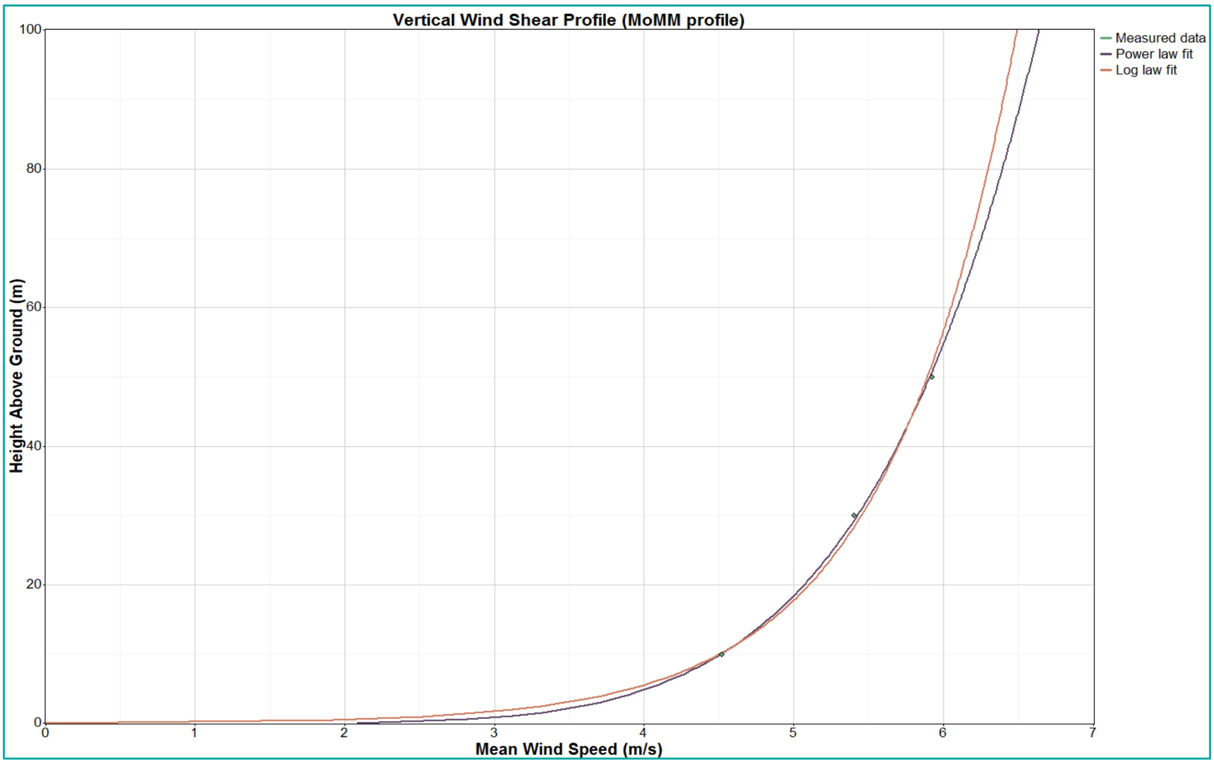


Figure 4.3: Vertical Wind Shear Profile

Table 4.4 Wind Characteristics of Vadgam Mast

Site Name/mast height	Vadgam - 50 m Height
Period of Data taken for Analysis	1st August 2006 – 31st July 2007
Data Recovery (50 m, 30 m, 10 m)	100.00 @ 50 m AGL, 100.00 @ 30 m AGL, 100.00 @ 10 m AGL,
Length of the Time stamp	10 minutes
Site Air density	1.217 kg/m^3
Power law	0.168
Annual mean wind speed **Aug 2006 - July 2007** **(50 m, 30m, 10 m)**	5.925 m/s @ 50 m AGL, 5.405 m/s @ 30 m AGL, 4.518 m/s @ 10 m AGL,
The predominant wind direction at the site	North - East, South - West

4.1.2 Khavi Region

The Month wise wind characteristics of Khavi site is shown below in Table 4.5.

Table 4.5: Month-wise Wind characteristics for Khavi

Months	100m combined (m/s)	80m (m/s)	50m (m/s)	10m (m/s)
Jan – 2014	6.372	5.769	5.015	3.230
Feb – 2014	5.332	4.915	4.322	2.646
Mar – 2014	5.616	5.204	4.555	2.760
Apr – 2014	5.115	4.733	4.186	2.551
May – 2014	6.120	5.756	5.228	3.487
Jun – 2014	8.892	8.574	8.088	5.848
Jul – 2014	7.154	7.026	6.266	4.383
Aug – 2014	5.974	4.631	5.064	3.337

Sep – 2014	5.335	5.016	4.480	2.846
Oct – 2014	4.011	3.816	3.438	2.214
Nov – 2014	4.181	3.573	3.762	2.152
Dec – 2014	6.756	5.224	6.219	3.157
Average	**5.913**	**5.370**	**5.065**	**3.226**

Based on the wind directional data it was seen that the predominant wind direction of the site is South of South West and the secondary wind direction is from North East. The wind rose diagram is shown below in Figure 4.4.

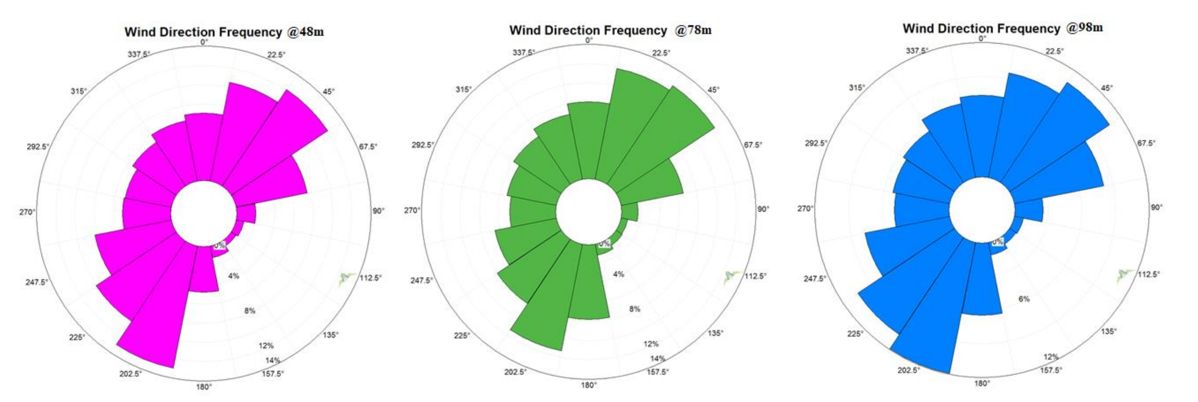


Figure 4.4: Wind Rose (January 2014 to December 2014)

The site air density calculated at the station was based on the measured Temperature, Pressure & Humidity data. The month-wise details of the environmental parameters are shown below in Table 4.6. Table 4.7 & 4.8 detail the Month-Wise Wind Power density and overall summary details at Khavi site respectively.

Table 4.6: Month-wise Environmental Parameter details

Month	Temperature (°C)	Air Density (kg/m^3)
Jan - 2014	19.77	1.202
Feb – 2014	22.30	1.187
Mar – 2014	26.42	1.168
Apr – 2014	30.08	1.149
May – 2014	31.46	1.140
Jun – 2014	31.18	1.137

Month	Temperature (°C)	Air Density (kg/m³)
Jul – 2014	28.76	1.146
Aug – 2014	27.75	1.154
Sep – 2014	27.50	1.158
Oct – 2014	29.04	1.156
Nov – 2014	26.68	1.169
Dec - 2014	20.78	1.196
Average	**26.82**	1.163

Table 4.7: Month-wise Wind Power Density

Month	100m (W/m^2)	80m (W/m^2)	50m (W/m^2)	10m (W/m^2)
Jan - 2014	212.03	158.27	98.56	28.63
Feb – 2014	149.81	114.55	72.13	18.06
Mar – 2014	164.98	127.27	77.25	17.18
Apr – 2014	147.09	114.89	72.41	16.11
May – 2014	208.98	173.60	130.34	42.04
Jun – 2014	550.49	496.67	426.71	166.32
Jul – 2014	300.38	284.05	206.99	73.80
Aug – 2014	184.59	97.24	115.25	35.10
Sep – 2014	144.83	120.99	85.50	24.37
Oct – 2014	56.98	48.21	34.13	9.39
Nov – 2014	74.53	40.53	50.93	8.81
Dec - 2014	250.14	105.71	190.04	24.79
All	**204.17**	**158.05**	**130.71**	**38.87**

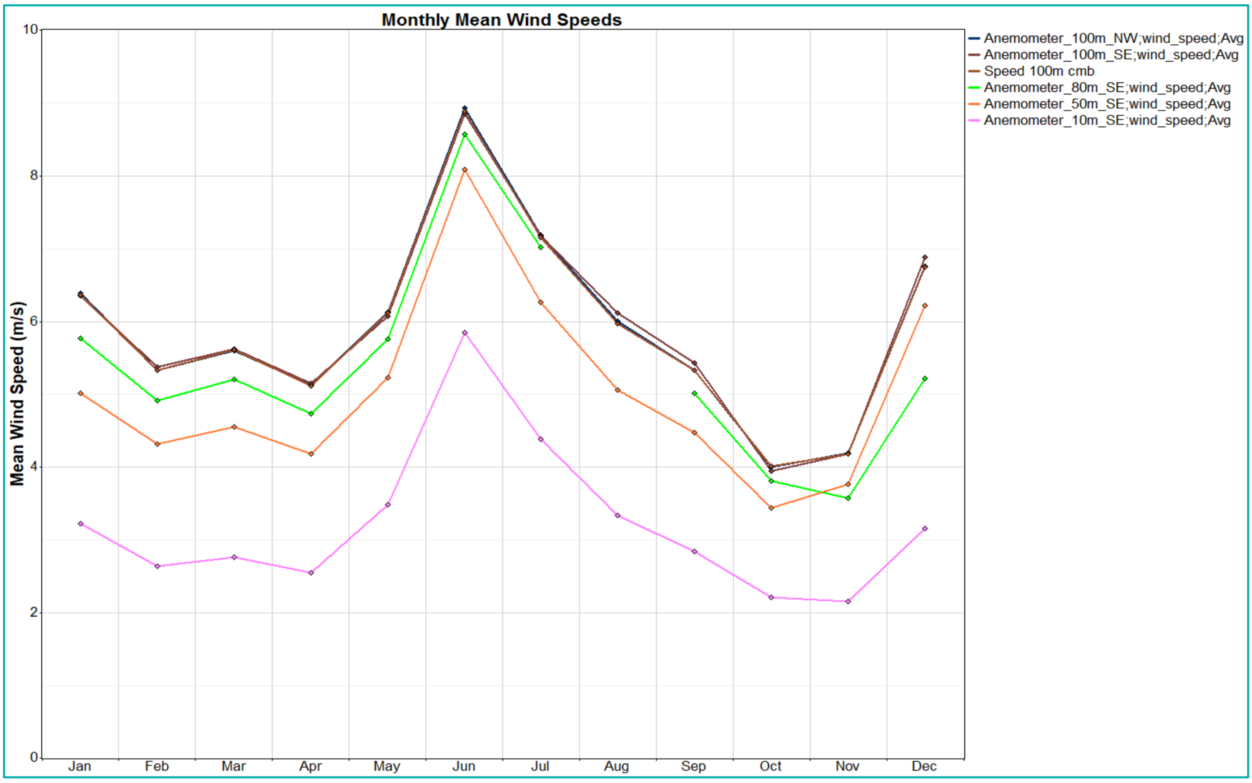


Figure 4.5: Monthly Mean Wind Speed

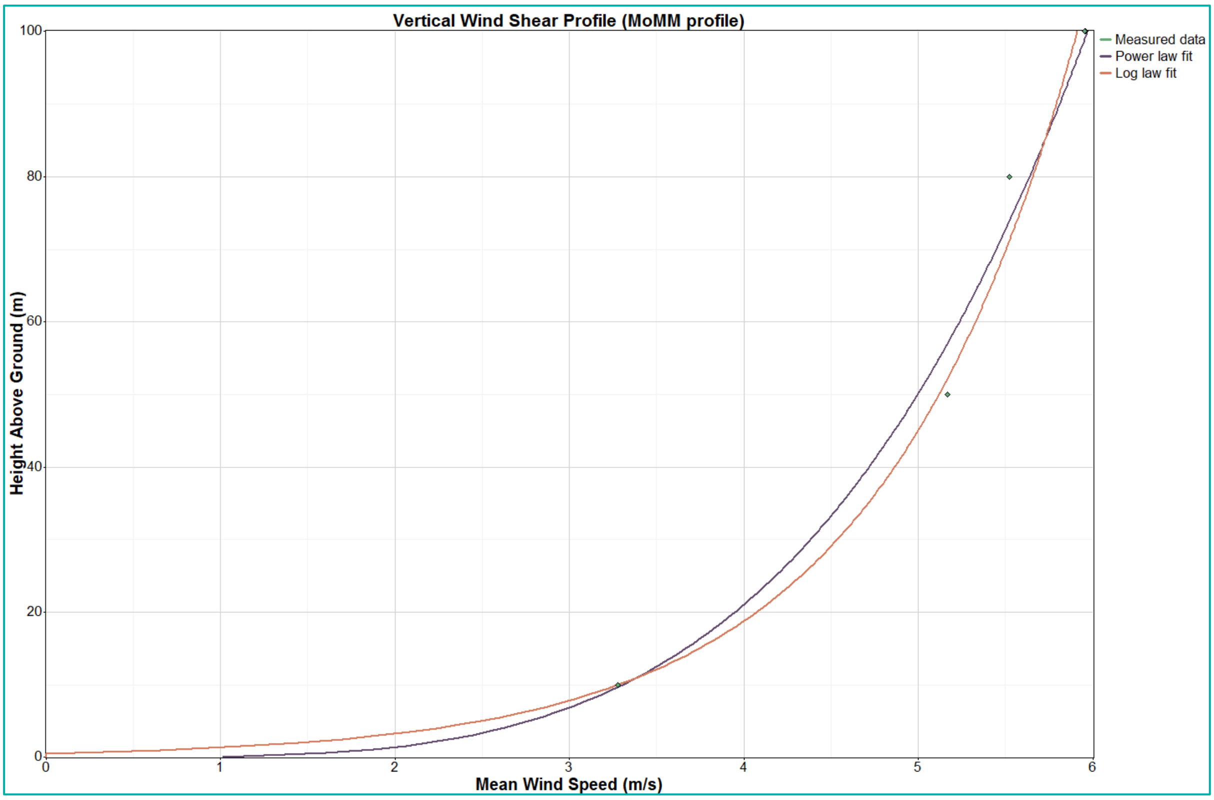


Figure 4.6: Vertical Wind Shear Profile

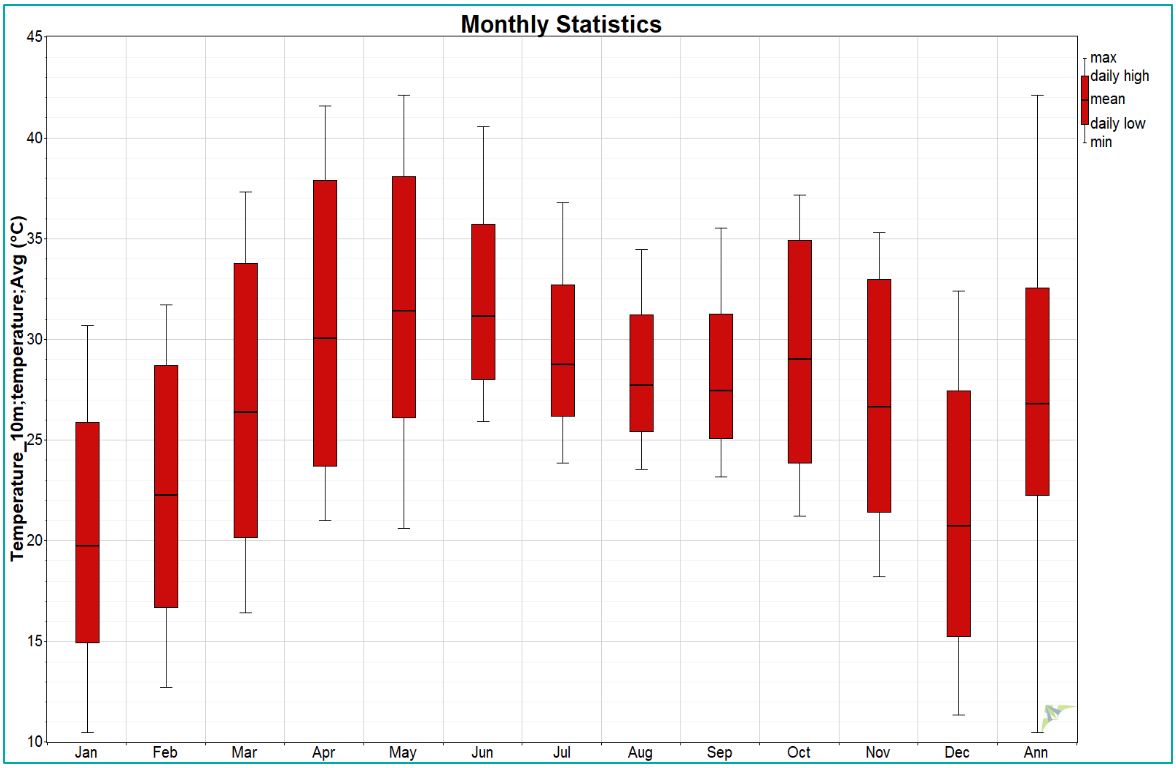


Figure 4.7: Temperature Profile for Khavi

Table 4.8 Wind Characteristics of Khavi Mast

Site Name/mast height	Khavi - 100m Height
Period of data taken for analysis	January 2014 – December 2014
Length of the Time stamp	10 minutes
Site Air density	1.163 kg/m3
Power law	0.259
Data Recovery(100 m, 80 m, 50 m,10 m)	99.64 @ 100m combined AGL, 93.99 @80m AGL, 98.94 @ 50m AGL, 99.29 @ 10m AGL
Annual mean wind speed **January 2014 – December 2014** **(100m)**	5.913 m/s @ 100m AGL, 5.370 m/s @80m AGL, 5.065 m/s @ 50m AGL, 3.226 m/s @ 10m AGL.

The predominant wind direction at the site	South of South West& North East

4.1.3 Kalpasar Region

The Month wise wind characteristics of Kalpasar site July 2022-June 2023 is shown below in Table 4.9 respectively.

Table 4.9: Month-wise Wind characteristics for Kalapasar

Months	100m Combined (m/s)	80m (m/s)	50m (m/s)	10m (m/s)
Jul	6.275	5.919	5.332	4.210
Aug	6.086	5.751	5.182	4.290
Sep	5.091	4.817	4.330	2.972
Oct	5.084	4.901	4.517	3.015
Nov	5.291	5.094	4.653	3.001
Dec	6.881	6.226	5.397	3.374
Jan	7.466	6.970	6.008	3.765
Feb	5.453	5.208	4.715	3.237
Mar	6.034	5.759	5.263	3.799
Apr	5.596	5.360	4.937	3.656
May	6.792	6.557	6.153	4.898
Jun	8.897	8.616	8.112	6.737
Average	**6.245**	**5.932**	**5.383**	**3.913**

Based on the wind directional data it was seen that the predominant wind direction of the site is West of South west & North East & North of North West and the secondary wind direction is from North East. The wind rose diagram is shown below in Figure 4.8.

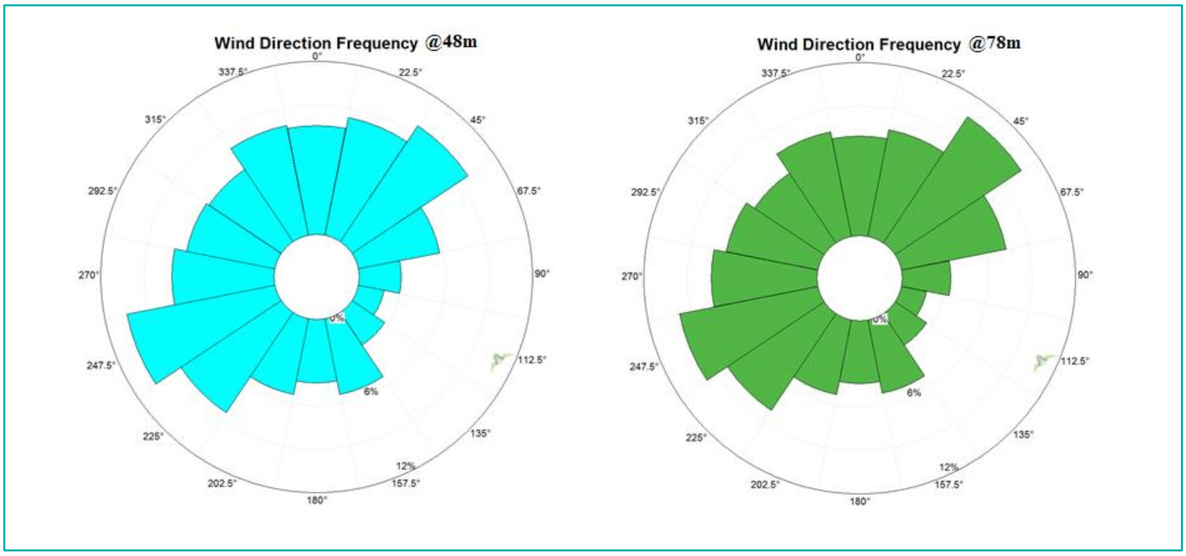


Figure 4.8: Wind Rose (July 2022 to July 2023)

The site air density calculated at the station was based on the measured Temperature, Pressure & Humidity data. The month-wise details of the environmental parameters are shown below in Table 4.10. Table 4.11 & 4.12 detail the Month-Wise Wind Power density and overall summary details at Kalpasar site respectively.

Table 4.10: Month-wise Environmental Parameter details

Month	Temperature (°C)	Pressure (mbar)	Air Density (kg/m^3)
Jul	27.77	1,001.30	1.151
Aug	28.18	1,001.20	1.150
Sep	28.42	1,005.00	1.153
Oct	28.09	1,006.80	1.171
Nov	25.19	-	1.174
Dec	22.38	1,012.30	1.187
Jan	19.18	1,014.40	1.204

Month	Temperature (°C)	Pressure (mbar)	Air Density (kg/m^3)
Feb	24.40	1,012.90	1.181
Mar	27.44	1,010.30	1.164
Apr	31.07	1,007.60	1.146
May	32.49	1,006.10	1.136
Jun	31.33	1,002.20	1.133
Average	**27.16**	**1,007.28**	**1.162**

Table 4.11: Month-wise Wind Power Density

Month	100m Combined (W/m^2)	80m (W/m^2)	50m (W/m^2)	10m (W/m^2)
Jan	199.49	170.33	130.08	70.89
Feb	197.62	167.97	125.82	71.34
Mar	108.36	89.87	64.08	23.20
Apr	118.85	105.30	80.01	26.36
May	136.28	120.79	86.52	21.95
Jun	271.18	200.58	122.75	28.62
Jul	363.78	289.57	169.90	44.74
Aug	162.00	138.28	93.86	29.66
Sep	222.01	190.42	140.04	58.69
Oct	156.55	135.91	104.24	47.43
Nov	291.79	263.79	223.24	128.00
Dec	618.39	569.21	488.47	294.77
All	237.19	203.5	152.41	70.47

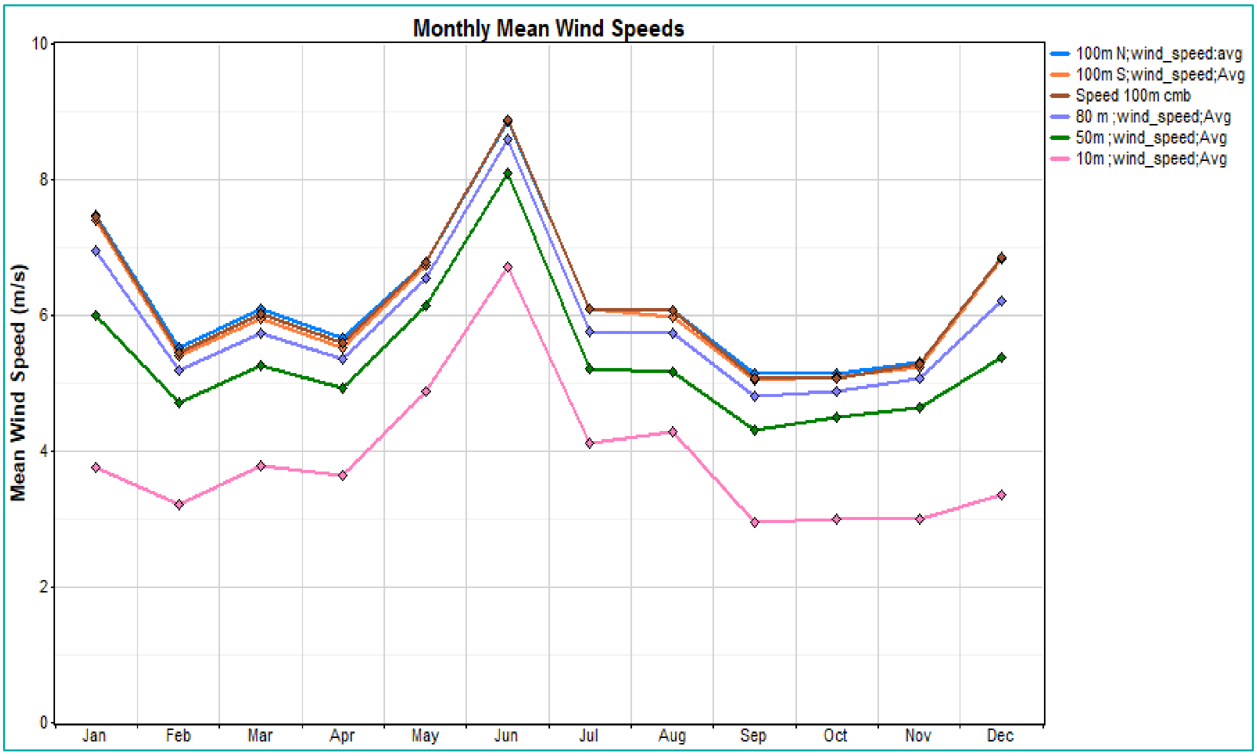


Figure 4.9: Monthly Mean Wind Speed

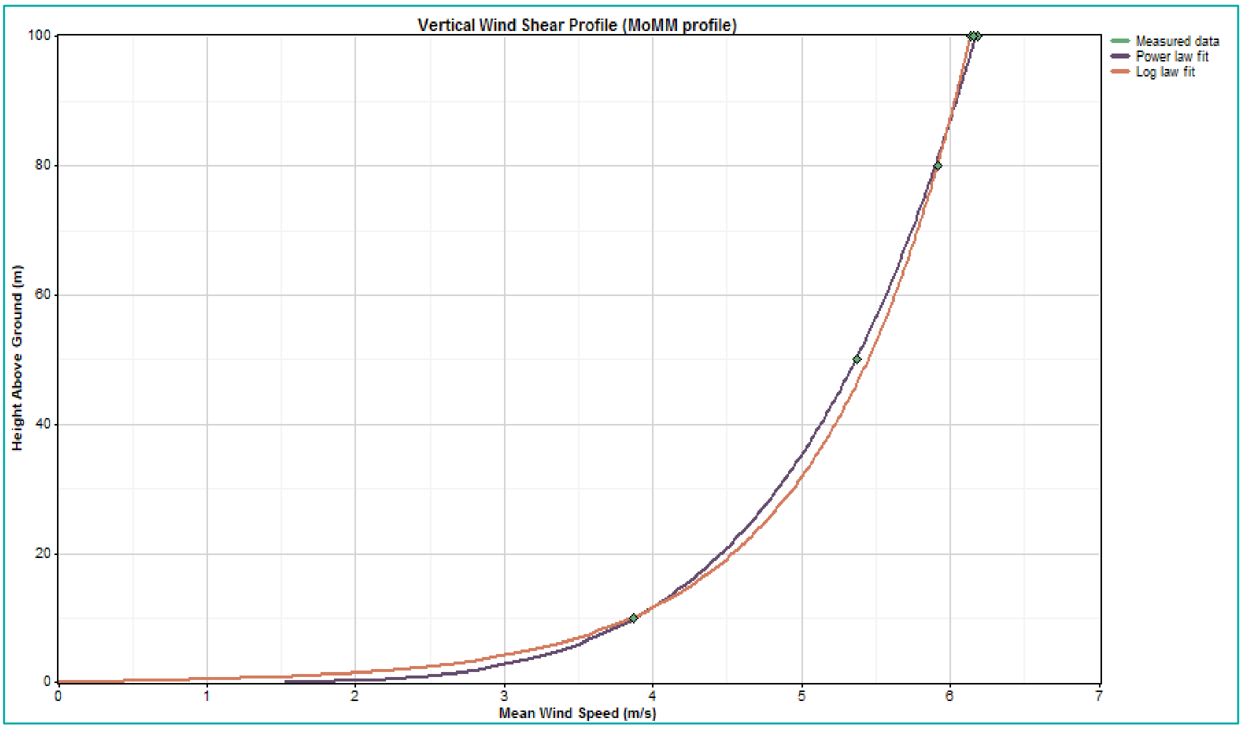


Figure 4.10: Vertical Wind Shear Profile

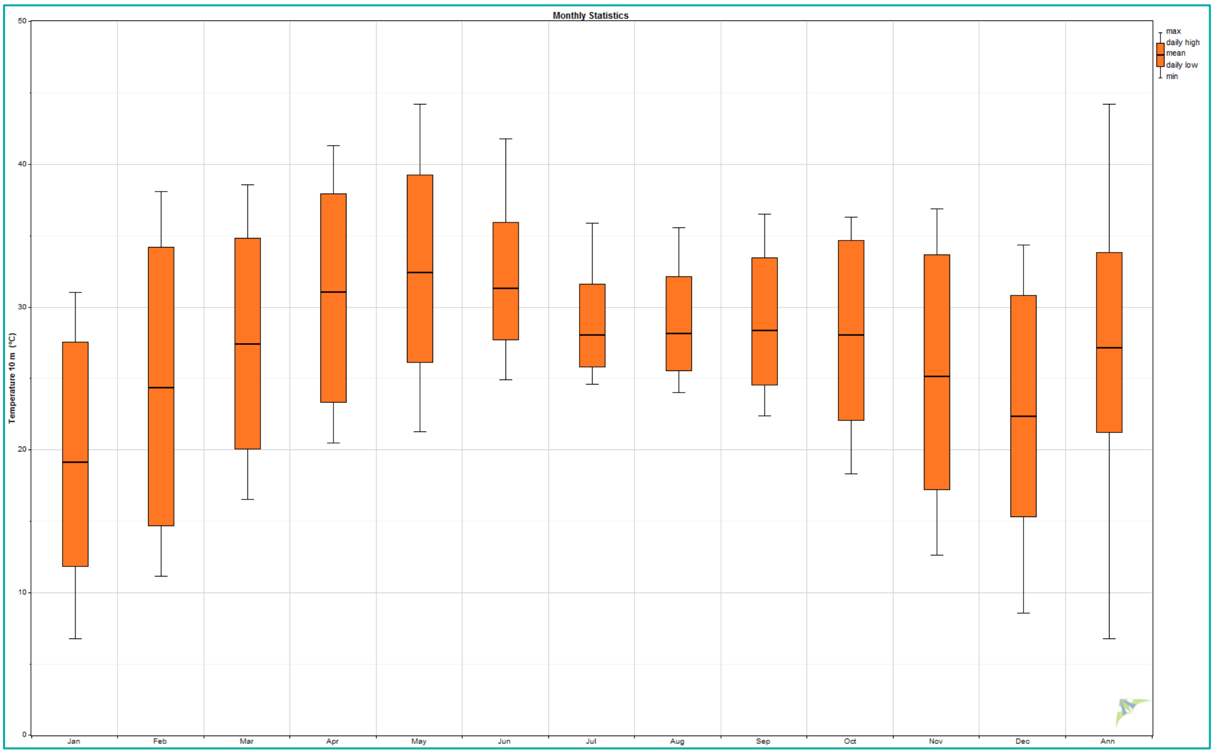


Figure 4.11: Temperature Profile for kalpasar

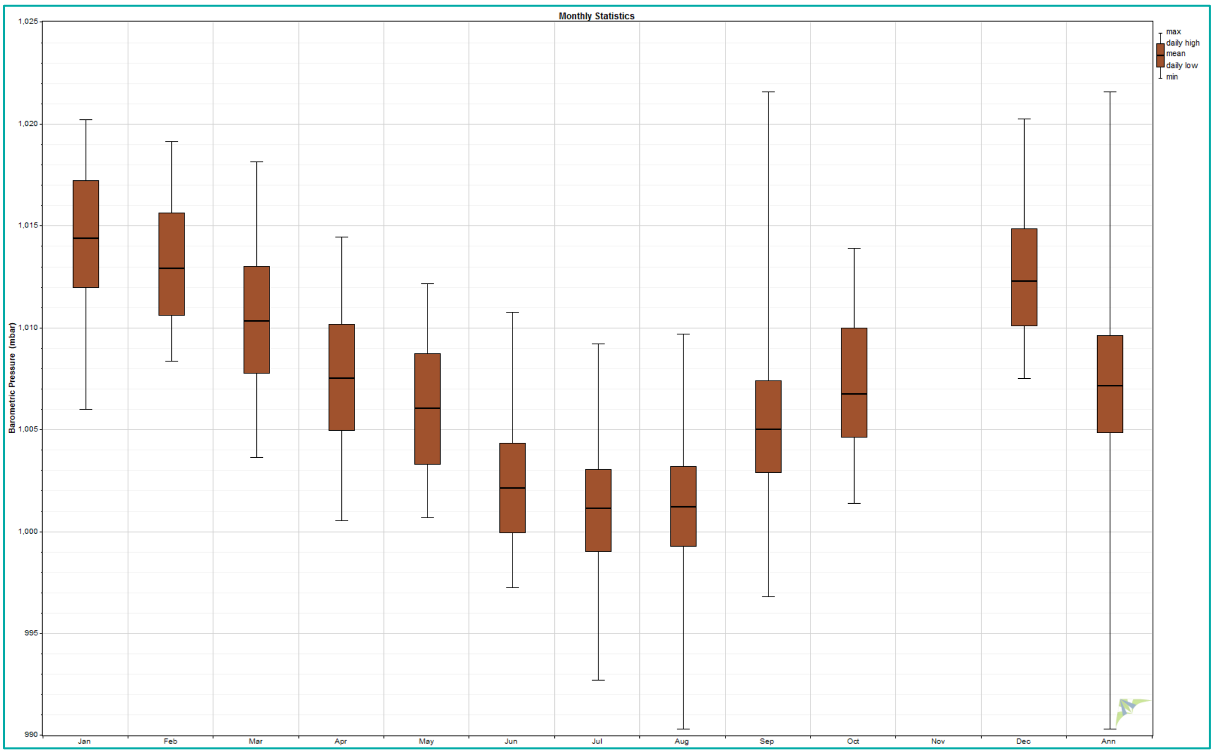


Figure 4.12: Pressure Profile for Kalpasar

Table 4.12: Summary of Results

Site Name/mast height	Kalpasar 100 meters
Period of Data taken for Analysis	July 2022 – June 2023
Data Recovery (100 Combined, 80 m, 50 m, 10 m)	99.49 @ 100m AGL 99.50 @ 80m AGL 99.20 @ 50m AGL, 97.93 @ 10m AGL,
Length of the Time stamp	10 mins
Site Air density	1.162 kg/m^3
Power law	0.202
Annual Mean Turbulence Intensity @ 15 m/s **(100 Combined, 80 m, 50 m)**	0.077@ 100 m AGL, 0.096 @ 80 m AGL 0.100 @ 50 m AGL
Annual mean wind speed **July 2022 – July 2023** **(100 Combined, 80 m, 50 m, 10 m)**	6.245 m/s@ 100m AGL, 5.932 m/s@ 80m AGL, 5.383 m/s@ 50m AGL, 3.913 m/s@ 10m AGL,
Annual mean wind power density **July 2022 – July 2023** **(100 Combined, 80 m, 50 m, 10 m)**	237.19 W/m^2 @ 100m AGL 203.5 W/m^2 @ 80m AGL, 152.41 W/m^2 @ 50m AGL, 70.47 W/m^2 @ 10m AGL,
The predominant wind direction at the site	West of South west&North East & North of north west

4.2 Site Description

4.2.1 Khavi:

The mast is located at Khavi village in Bharuch district, Gujarat. Based on the satellite images, the site is found to be 3.13 km Northwest of Khavi village and found to be distributed over a homogeneous / flat terrain with good exposure to the wind flow and the environment is found to be open and barren with gentle undulations. National Highway 228 is the nearest highway to the proposed site and the nearest railway station and airport is Khambhat railway station and Vadadora airport. The details of the mast are as follows,

Name of the Met Mast	Latitude (N)	Longitude (E)	Elevation (amsl)	Mast Height (m)	Data Period
Khavi	22°11’14.60”	72°39’59.50”	29	100	Jan 2014–Dec 2014

4.2.2 Vadgam:

The mast is located at village in Banaskantha district, Gujarat. Based on the satellite images, the site is found to be 7.58 km North of Mitali village and found to be distributed over a homogeneous / flat terrain with good exposure to the wind flow and the environment is found to be open and barren with gentle undulations. National Highway 751 is the nearest highway to the proposed site and the nearest railway station and airport is Umardashi railway station and Sardar Vallabhbhai Patel International Airport. The details of the mast are as follows,

Name of the Met Mast	Latitude (N)	Longitude (E)	Elevation (amsl)	Mast Height (m)	Data Period
Vadgam	22°20’25.00”	72°34’33.00”	10	50	Aug 2006- July 2007

4.2.3 Kalpasar:

The mast is located in Ahmedabad district, Gujarat. Based on the satellite images, the site is found to be 8 km East of Hebatpur village and it is distributed over a homogeneous / flat terrain with good exposure to the wind flow and the environment is found to be open and barren with gentle undulations. National Highway 751 is the nearest highway to the proposed site and the nearest railway station and airport is Dhandhuka Railway Station and Sardar Vallabhbhai Patel International Airport. The details of the mast are as follows,

Name of the Met Mast	Latitude (N)	Longitude (E)	Elevation (amsl)	Mast Height (m)	Data Period
Kalpasar	22°8’47.26”	72°10’57.61”	7	100	July 2022-June 2023

4.3 Measurement Setup

In order to understand the wind climate and wind potential of the Kalpasar region, NIWE had engaged to carry out met-mast based wind measurement at the site. In this regard, NIWE has installed a 100 m mast at Kalpasar region in July 2022 and the measurement is completed on June 2023.

4.3.1 On-site wind measurement – Kalpasar Dam

NIWE has installed a 100 m tall Lattice guyed mast tower in the region of Kalpasar nearer to the boundary of the Kalpasar in order to understand the wind characteristics of proposed region. The wind data measurement at Kalpasar mast was initiated on July-2022 and calibrated sensors were used for the study. The anemometers (for wind speed measurement) were placed at multiple height levels viz. 100 m N & S, 80 m, 50 m & 10m and wind vanes (for wind direction measurement) were placed at 98 m, 78 m and 48 m respectively. 98m wind vane is not working properly and so 78m wind vane has been considered for the analysis.

The data measurement from 05-07-2022 to 30-06-2023 have been used for theanalysis. Based on the analysis it was found that the data availability in anemometer sensor at 100m was about 99.49% for the entire available period. The details of Kalpasar mast (proposed mast) and the mast photo are shown Table 4.13 and Figure 4.13.

Figure 4.13: Kalpasar met mast

4.4 Analysis

The wind measurement at the site has been carried out for a period of one year, whereas the operational period of the wind farm is 20 years. Hence it is imperative to understand the long term variation of wind characteristics with the support of available data sources in order to reduce the uncertainty in the long term estimation and to mitigate the risk of underperformance of the wind farm. In this regard, ERA5 reanalysis data has been used in the present study to carry out the long term correction through MCP (Measure –Correlate-Predict) technique.

4.4.1 Long term Correction of Actual Measurement of Vadgam Region

Under the MCP analysis, sector-wise (16 sectors) daily mean wind speed data from the actual mast measurement (1st August 2006 to 31st July 2007) has been correlated with the model data ERA-5 (July 2003 to June 2023) of 100m using Linear Least Square (LLS) correlation algorithm. Based on the daily correlation analysis, the coefficient of determination (R^2) for wind speed is found to be **0.499** and the LCA factor was found to be **1.015**. The 50m data was extrapolated to the actual hub height of the Wind Turbine Models (140m & 127.5m) and used for energy estimation analysis.

With regard to long term correction of Vadgam wind data, the correlation proves to be weak, showing R^2 vaule of 0.499 only. Since, correlation analysis with MERRA2 and EMD WRF has also yielded similar results, the long-term scaling has been carried out using the ERA5 data, even though the correlation co-efficient is lesser than the recommended value. Further, with regard to Vadgam site, the 50m data had to be extrapolated to 140m and 127.5m, which is a violation to the MEASNET guideleins for vertical extrapolation. However, due to non-availability of measured data at the site, the analysis has been carried out using the extrapolated data from 50m mast and the same is expected to add additional uncertainty to the analysis. Hence, the results derived suing Vadgam mast can only be considered as indicative. It is recommended to carry out a representative (minimum 100m high mast) measurement at Vadgam site in order to enhance the accuracy of the analysis.

4.4.1.1 Vadgam Model A

The scaled wind characteristics at 140m to represent the long term wind climate of the Vadgam site is shown in Figures 4.14 and 4.15 below.

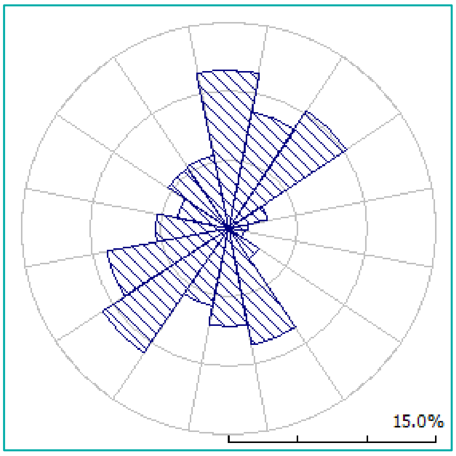


Figure 4.14: Wind rose

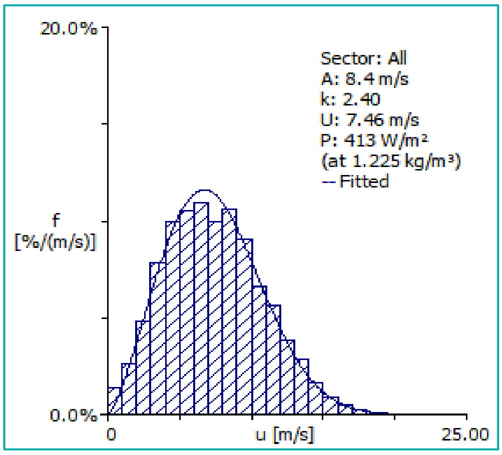


Figure 4.15: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.17 and Table 4.18 respectively.

Table 4.17: Summary of Vadgam Model A wind data (Air density correction is done in WPD (P) at 140m agl)

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	8.1	8.6	9.2	7.4	7.2	6.2	6.2	9.7	8.7	7.7	8.7	8.5	8.3	8.5	7.7	7.0
k	2.04	2.29	2.38	1.81	1.99	1.79	2.30	2.50	2.63	2.84	3.47	2.93	2.78	2.75	2.14	1.97
U	7.13	7.66	8.14	6.57	6.42	5.54	5.47	8.64	7.73	6.82	7.87	7.62	7.41	7.53	6.85	6.22
P*	417	465	541	369	312	225	169	622	431	282	390	386	367	387	352	286
f	11.6	8.7	10.3	2.9	1.4	1.2	2.6	8.7	7.2	5.8	11.0	9.0	5.3	3.8	5.3	5.4

A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and percent (f).

Table 4.18: Wind Speed Frequency Distribution of Vadgam Model A wind data at 140m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	14	1	2	16	41	10	44	7	13	8	9	15	17	30	39	17	14
2.0	38	34	12	32	33	58	44	13	24	40	17	15	17	27	28	51	26
3.0	85	50	28	63	99	115	83	29	46	49	26	28	20	48	60	82	48
4.0	77	74	76	123	124	183	135	94	69	71	58	52	78	60	71	114	79
5.0	113	111	105	142	157	115	153	83	65	97	71	98	102	60	110	133	100
6.0	107	104	94	119	58	135	153	85	110	126	89	99	96	106	125	135	105
7.0	98	97	110	103	74	115	140	81	113	148	104	128	130	121	123	80	109
8.0	86	89	88	55	58	77	87	83	105	136	142	117	130	112	80	63	100

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
9.0	81	77	101	87	91	67	61	71	112	138	159	121	133	130	103	105	106
10.0	77	89	96	47	83	48	48	69	91	77	129	122	91	112	73	91	91
11.0	61	66	68	55	58	10	17	99	78	40	74	81	74	66	47	40	66
12.0	48	73	58	63	58	10	31	62	58	38	67	71	50	57	63	30	57
13.0	45	60	47	40	41	29	4	53	56	16	31	22	33	24	28	36	38
14.0	30	32	38	24	17	10	0	89	37	10	15	14	17	21	28	6	28
15.0	17	24	39	16	0	10	0	34	13	4	6	8	9	12	13	6	16
16.0	9	12	16	0	8	0	0	28	8	2	2	5	0	9	6	11	9
17.0	6	1	13	12	0	10	0	17	2	0	1	3	0	0	2	0	5
18.0	7	5	9	4	0	0	0	3	0	0	0	1	0	3	0	0	3
19.0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0

4.4.1.2 Vadgam Model B

The scaled wind characteristics at 127.5m height to represent the long term wind climate of the Vadgam site is shown in Figures 4.16 and 4.17 below.

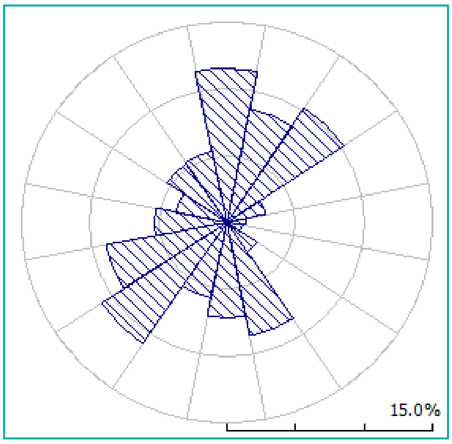


Figure 4.16: Wind rose

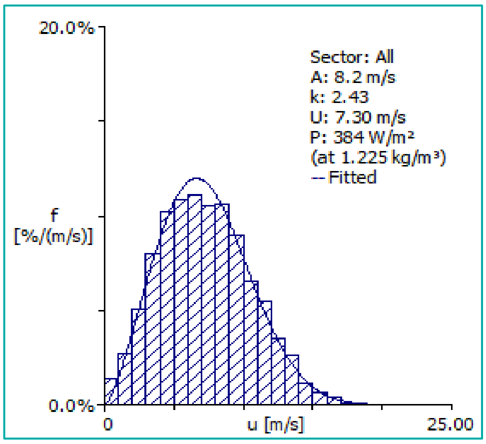


Figure 4.17: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.19 and Table 4.20 respectively.

Table 4.19: Summary of Vadgam Model B wind data (Air density correction is done in WPD (P) at 127.5m agl)

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	7.8	8.4	8.9	7.2	7.1	6.1	6.1	9.6	8.6	7.6	8.7	8.5	8.2	8.2	7.6	6.9
k	2.09	2.39	2.42	1.86	2.09	1.78	2.35	2.49	2.63	2.95	3.49	2.93	2.76	2.72	2.24	2.04
U	6.91	7.43	7.87	6.41	6.28	5.40	5.43	8.56	7.63	6.76	7.79	7.54	7.28	7.30	6.73	6.11
P*	371	411	482	334	278	209	162	607	414	268	377	373	349	355	321	261
f	11.6	8.7	10.3	2.9	1.4	1.2	2.6	8.7	7.2	5.8	11.0	9.0	5.3	3.8	5.3	5.4

A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and per cent (f).

Table 4.20: Wind Speed Frequency Distribution of Vadgam Model B wind data at 127.5m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	14	1	2	16	41	10	44	7	13	8	9	15	17	30	41	17	14
2.0	39	34	13	32	41	58	44	13	24	38	17	17	17	27	28	51	27
3.0	90	54	30	71	91	135	87	32	50	55	26	29	20	48	60	84	51
4.0	77	77	79	142	124	163	144	94	65	71	58	51	80	60	73	114	80
5.0	116	114	105	138	157	144	144	83	69	101	75	99	107	66	108	137	102
6.0	116	107	100	115	58	115	153	82	118	125	95	107	100	106	129	133	109
7.0	97	98	111	95	91	115	144	82	112	148	106	131	139	142	127	82	111
8.0	93	97	99	79	83	87	92	86	107	150	140	112	122	112	88	80	105
9.0	71	83	105	55	83	58	48	78	115	130	160	128	130	130	110	114	106
10.0	82	85	99	67	58	38	52	70	93	77	125	119	100	106	63	72	90
11.0	63	75	59	47	66	19	22	90	69	34	78	80	72	73	56	38	65
12.0	55	77	65	67	74	10	26	63	53	40	58	61	41	42	47	36	55
13.0	31	44	33	32	25	19	0	58	65	12	34	27	37	30	39	23	35
14.0	30	30	51	28	0	10	0	87	32	10	8	9	9	6	17	8	26
15.0	12	15	20	0	8	10	0	32	8	0	8	6	7	15	11	11	12
16.0	7	4	16	4	0	10	0	24	6	2	0	5	0	3	2	0	6
17.0	6	5	8	12	0	0	0	17	2	0	1	3	0	0	0	0	4
18.0	1	0	4	0	0	0	0	1	0	0	0	1	0	3	0	0	1
19.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0

4.4.2 Long term Correction of Actual Measurement of Khavi Region

Under the MCP analysis, sector-wise (16 sectors) daily mean wind speed data from the actual mast measurement (1st January 2014 to 31st December 2014) has been correlated with the model data ERA-5 (July 2003 to June 2023) of 100m using Linear Least Square (LLS) correlation algorithm. Based on the daily correlation analysis, the coefficient of determination (R^2) for wind speed is found to be **0.852** and the LCA factor was found to be **1.012**. Subsequently, based on the relationship the 20 years long term data has been synthesized. The 100m data was extrapolated to the actual hub height of the Wind Turbine Models and used for energy estimation analysis.

4.4.2.1 Khavi Model A

The scaled wind characteristics at 140m height to represent the long term wind climate of the Khavi site is shown in Figures 4.18 and 4.19 below.

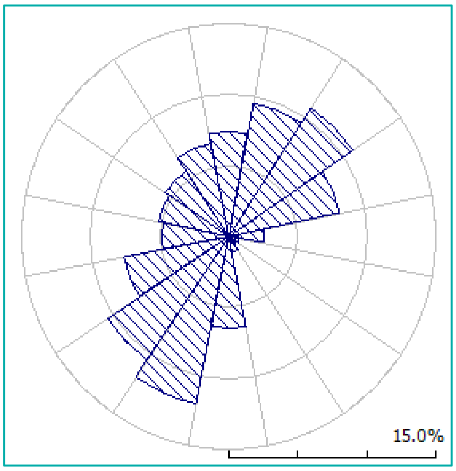


Figure 4.18: Wind rose

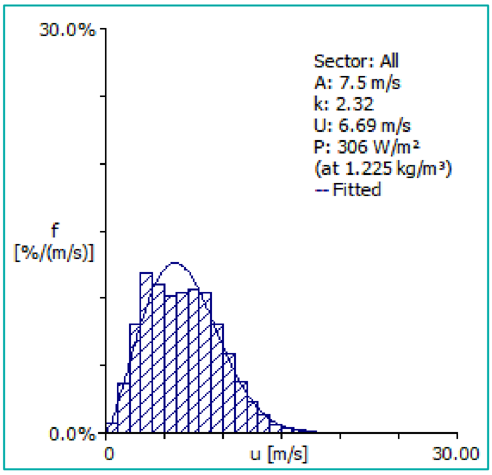


Figure 4.19: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.21 and Table 4.22 respectively.

Table 4.21: Summary of Khavi Model A wind data (Air density correction is done in WPD (P) at 140m agl)

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	4.9	6.4	7.5	7.4	6.4	4.9	4.8	6.1	10.4	9.3	8.4	8.0	6.6	6.3	6.4	5.9
k	1.54	2.08	2.40	2.53	1.74	1.44	1.51	2.09	3.23	3.02	3.13	2.88	1.98	2.04	2.08	1.67
U	4.43	5.64	6.63	6.55	5.73	4.45	4.32	5.42	9.35	8.32	7.52	7.13	5.87	5.56	5.70	5.23
P*	140	202	290	269	256	156	133	179	676	493	357	319	239	197	209	206
f	7.3	9.5	10.8	8.2	2.5	0.8	0.7	1.1	6.5	12.0	10.4	7.7	4.9	5.2	5.5	6.7

A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and per cent (f).

Table 4.22: Wind Speed Frequency Distribution of Khavi Model A wind data at 140m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	7	6	5	10	26	37	55	47	6	4	5	3	7	8	10	9	8
2.0	56	47	38	37	85	171	155	87	16	12	15	16	35	43	53	51	37
3.0	159	135	93	63	145	164	187	109	15	19	28	41	77	121	110	115	81
4.0	253	173	126	117	125	162	137	115	28	27	60	93	167	168	142	161	119
5.0	178	112	120	115	112	107	129	119	45	36	79	98	164	134	128	192	110
6.0	98	105	89	120	90	94	84	155	64	79	96	102	111	122	138	131	102
7.0	81	97	82	109	103	39	61	144	72	115	145	140	114	99	99	86	104
8.0	54	100	91	108	74	59	55	52	99	159	153	147	96	74	95	74	107
9.0	38	91	115	100	44	37	42	38	120	172	147	127	73	89	91	47	104
10.0	25	51	92	93	48	43	42	48	114	131	116	90	53	68	59	46	81
11.0	20	34	64	68	40	46	29	60	120	97	69	58	39	39	29	37	59
12.0	13	26	44	37	47	27	5	10	99	57	43	40	28	18	21	20	38
13.0	10	15	24	18	37	7	13	10	75	32	17	25	22	9	12	12	23
14.0	4	7	10	4	11	7	5	5	53	21	13	12	9	6	13	10	13
15.0	0	0	4	2	12	0	0	2	35	12	7	6	3	1	1	6	7
16.0	1	0	1	0	1	0	0	0	18	12	4	1	1	0	0	1	3
17.0	1	0	0	0	0	0	0	0	11	8	3	1	0	0	0	0	2
18.0	0	0	0	0	0	0	0	0	8	4	0	0	0	0	0	0	1
19.0	0	0	0	0	0	0	0	0	3	2	0	0	1	0	0	0	1
20.0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
21.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
22.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
26.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.4.2.2 Khavi Model B

The scaled wind characteristics at 127.5m height to represent the long term wind climate of the Khavi site is shown in Figures 4.20 and 4.21 below.

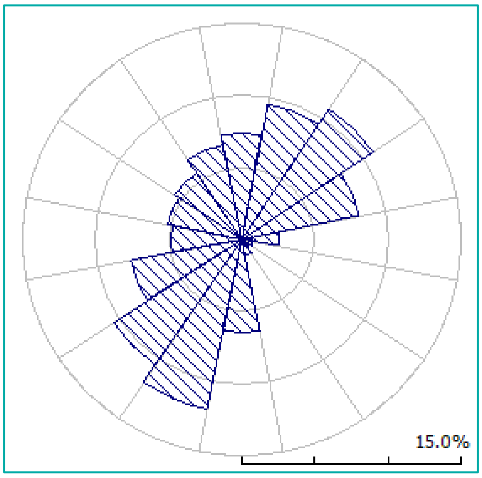


Figure 4.20: Wind rose

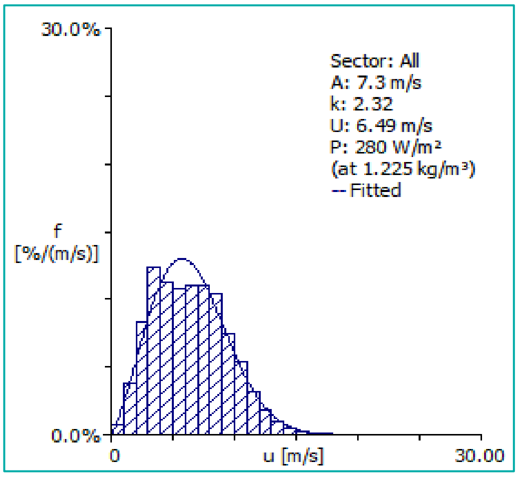


Figure 4.21: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.23 and Table 4.24 respectively.

Table 4.23: Summary of Khavi Model B wind data (Air density correction is done in WPD (P) at 127.5m agl)

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	4.8	6.2	7.2	7.2	6.2	4.7	4.7	6.0	10.2	9.1	8.2	7.7	6.4	6.1	6.3	5.7
k	1.60	2.10	2.46	2.61	1.77	1.46	1.55	2.09	3.21	2.99	3.13	2.87	1.97	2.08	2.14	1.72
U	4.34	5.47	6.43	6.38	5.53	4.29	4.18	5.30	9.17	8.09	7.32	6.91	5.67	5.40	5.58	5.07
P*	125	182	260	244	225	138	116	166	641	457	330	291	217	177	191	181
f	7.3	9.5	10.8	8.2	2.5	0.8	0.7	1.1	6.5	12.0	10.4	7.7	4.9	5.2	5.5	6.7

A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and per cent (f).

Table 4.24: Wind Speed Frequency Distribution of Khavi Model B

Wind data at 127.5m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	7	7	5	10	26	37	55	48	6	4	5	3	7	8	10	10	8
2.0	58	49	39	37	88	171	155	87	16	12	15	17	36	45	55	53	38
3.0	165	138	96	67	152	174	192	112	17	19	30	42	82	127	112	120	84
4.0	266	179	131	120	130	164	147	119	29	30	63	98	174	169	144	170	124
5.0	173	115	122	120	107	119	124	129	49	39	82	99	167	142	135	197	113
6.0	103	111	89	122	101	84	89	165	66	85	112	119	120	129	141	126	108
7.0	77	100	87	112	104	50	61	127	79	134	150	149	117	100	105	94	110
8.0	57	103	101	114	65	46	68	50	108	168	155	143	88	85	98	69	110
9.0	33	88	123	104	51	34	39	42	114	169	152	129	78	84	92	46	105
10.0	21	45	87	94	45	62	39	52	125	122	100	78	39	53	44	48	75
11.0	20	30	61	58	42	30	8	48	107	89	69	55	39	32	25	31	54
12.0	10	21	34	30	53	23	8	7	94	46	30	36	29	15	16	15	32
13.0	7	11	18	8	20	7	8	10	73	31	15	17	14	8	16	11	19
14.0	1	3	5	3	15	0	5	3	53	16	11	11	6	3	7	7	10
15.0	1	0	2	0	1	0	0	2	28	13	6	3	2	0	0	1	5
16.0	0	0	0	0	0	0	0	0	17	12	3	1	0	0	0	0	3
17.0	1	0	0	0	0	0	0	0	9	6	2	1	0	0	0	0	2
18.0	0	0	0	0	0	0	0	0	8	4	0	0	0	0	0	0	1
19.0	1	0	0	0	0	0	0	0	1	2	0	0	1	0	0	0	0
20.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
22.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.4.3 Long term Correction of Actual Measurement of Kalpasar Region:

Under the MCP analysis, sector-wise (16 sectors) daily mean wind speed data from the actual ERA-5 measurement (July 2003 to June 2023) has been correlated with the actual Met Mast Measurement (July 2022 to June 2023) of 100m using Linear Least Square (LLS) correlation algorithm. Based on the daily correlation analysis, the coefficient of determination (R^2) for wind speed is found to be **0.794** and the LCA factor was found to be **1.015**. Subsequently, based on the relationship the 20 years long term data has been synthesized. The scaled 100m data was extrapolated to the actual hub height of the Wind Turbine Models and used for energy estimation analysis.

4.4.3.1 Kalpasar Model A

The scaled wind characteristics at 140m height to represent the long term wind climate of the Kalpasar site is shown in Figures 4.22 and 4.23 below.

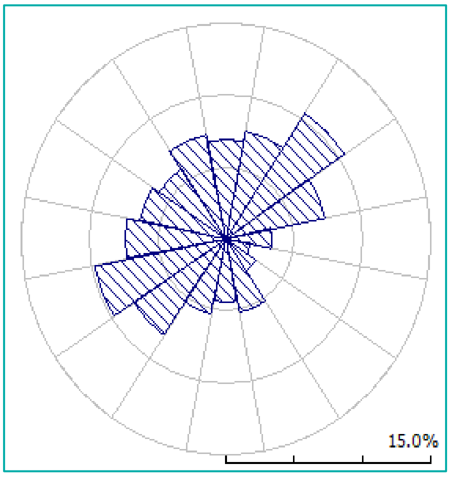


Figure 4.22: Wind rose

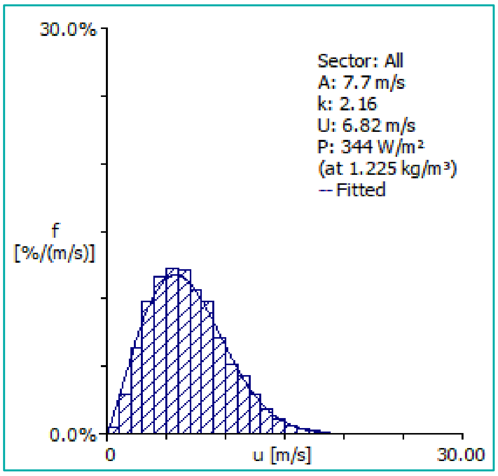


Figure 4.23: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.25 and Table 4.26 respectively.

Table 4.25: Summary of Kalpasar Model A wind data at 140m agl)

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	7.7	7.9	8.2	7.1	5.6	4.6	5.4	8.7	9.6	9.5	8.0	8.1	7.3	7.2	7.3	7.1
k	1.94	2.24	2.50	2.10	1.94	1.82	2.44	2.69	2.47	2.27	2.57	2.58	2.66	2.62	2.04	1.79
U	6.85	6.95	7.32	6.30	4.99	4.08	4.83	7.75	8.47	8.40	7.08	7.19	6.48	6.43	6.50	6.35
P*	388	354	378	279	150	88	111	428	594	617	337	351	251	248	316	338
f	6.9	7.6	10.5	7.4	3.4	1.8	2.7	5.2	4.4	5.3	8.1	9.8	7.3	6.5	5.8	7.4

**A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and per cent (f).*

Table 4.26: Wind Speed Frequency Distribution of Kalpasar Model A wind data at 140m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	3	4	2	4	7	28	12	12	8	8	3	5	4	4	7	4	5
2.0	29	27	19	19	51	85	59	31	32	30	24	17	26	35	38	31	29
3.0	73	65	57	55	133	148	98	44	51	45	47	39	58	67	81	73	63
4.0	103	108	102	136	177	269	189	63	64	66	71	59	89	95	86	104	98
5.0	125	126	111	143	179	214	201	87	75	52	90	88	129	124	123	133	117
6.0	121	117	98	138	167	126	186	91	64	65	130	124	143	127	135	165	123
7.0	109	90	97	136	99	59	118	103	76	111	144	160	145	160	135	114	121
8.0	84	78	111	105	75	16	70	113	100	108	147	146	124	127	98	76	107
9.0	83	93	112	93	45	11	31	109	122	123	118	128	115	104	73	71	98
10.0	72	86	80	51	24	13	20	90	98	113	90	72	66	70	65	50	72
11.0	43	76	58	39	20	18	7	74	73	62	66	57	45	33	51	36	51
12.0	41	64	61	26	6	4	7	76	69	57	32	41	33	27	34	45	43
13.0	39	28	43	22	5	6	1	61	39	46	12	30	14	16	27	39	29
14.0	35	19	28	12	2	2	0	25	36	27	7	16	4	6	27	30	19
15.0	23	7	15	9	3	1	0	14	31	25	4	6	3	2	10	20	11
16.0	11	8	2	7	4	0	0	3	28	17	2	4	0	1	7	4	6
17.0	2	2	1	3	2	0	1	3	20	14	4	4	0	1	2	3	3
18.0	3	0	1	1	1	0	0	1	10	12	5	2	0	0	0	1	2
19.0	1	1	0	0	0	0	0	0	2	3	2	1	0	0	1	1	1
20.0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
22.0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
23.0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
24.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.4.3.2 Kalpasar Model B

The scaled wind characteristics at 127.5m height to represent the long term wind climate of the Kalpasar site is shown in Figures 4.24 and 4.25 below.

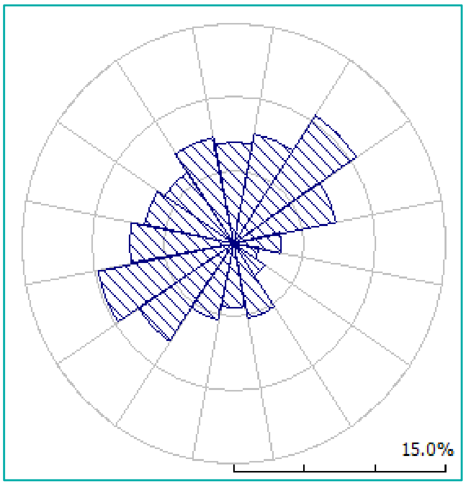


Figure 4.24: Wind rose

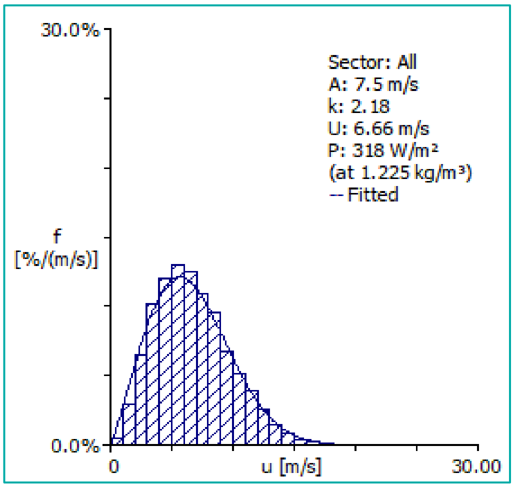


Figure 4.25: Wind Speed Frequency Distribution

The summary of wind data characteristics and wind speed frequency distribution are given in Table 4.27 and Table 4.28 respectively.

Table 4.27: Summary of Kalpasar Model B wind data at 127.5m agl

-	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	7.5	7.6	8.0	7.0	5.5	4.5	5.4	8.6	9.4	9.3	7.8	7.9	7.1	7.0	7.1	7.0
k	2.00	2.31	2.55	2.18	1.97	1.81	2.47	2.67	2.40	2.21	2.50	2.55	2.66	2.65	2.09	1.87
U	6.67	6.75	7.09	6.16	4.91	4.01	4.79	7.68	8.31	8.20	6.91	7.03	6.32	6.26	6.32	6.22
P*	347	315	339	252	141	84	107	418	572	588	319	331	234	228	282	301
f	6.9	7.6	10.5	7.4	3.4	1.8	2.7	5.2	4.4	5.3	8.1	9.8	7.3	6.5	5.8	7.4

A and U are given in m/s, P in W/m² and the frequencies of occurrence in per mile and per cent (f).

Table 4.28: Wind Speed Frequency Distribution of kalpasar Model B wind data at 127.5m agl

U	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	All
1.0	3	4	2	3	6	28	10	11	9	9	3	4	4	4	7	3	5
2.0	30	27	21	19	56	85	61	34	31	29	25	18	25	35	39	31	30
3.0	73	69	58	57	133	150	103	44	54	48	50	40	62	69	84	76	65
4.0	107	112	104	140	182	284	191	65	64	68	73	62	93	100	89	107	102
5.0	127	132	115	149	180	204	202	88	77	55	96	94	134	127	124	139	120
6.0	127	117	101	143	172	123	183	95	71	72	141	137	152	139	150	166	130
7.0	112	93	110	137	94	57	126	102	77	123	148	160	151	168	139	117	126
8.0	86	87	116	114	74	16	61	114	112	107	145	152	124	123	93	80	109
9.0	88	95	111	88	45	8	32	108	117	125	111	116	107	98	73	72	95
10.0	70	90	73	48	24	17	17	87	89	99	86	70	62	59	61	45	67
11.0	40	78	68	33	14	15	8	76	74	58	64	53	44	33	49	48	52
12.0	43	50	57	27	6	6	7	75	65	56	24	38	24	23	35	40	39
13.0	38	23	36	18	3	3	0	59	39	45	9	28	11	14	29	36	26
14.0	29	9	22	10	1	3	0	25	36	25	8	13	3	3	17	27	15
15.0	17	9	4	8	3	0	0	12	30	25	3	5	2	2	7	6	8
16.0	4	2	1	4	4	0	0	2	25	16	2	4	0	0	1	4	4
17.0	3	1	1	2	2	0	1	3	19	14	5	3	0	1	1	1	3
18.0	1	0	1	0	0	0	0	1	7	11	4	3	0	1	0	1	2
19.0	0	1	0	0	0	0	0	0	2	3	1	0	0	0	0	0	0
20.0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
22.0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
24.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5. CONFIGURATION

5.1 Solar Energy

This chapter briefs about the design of solar farm layout prepared at the Kalpasar site. In this study, the solar farm layout is designed subsequent to the design of the wind farm layout (detailed in trailing section). In order to avoid the shadow impact, a circular mask has been applied to each wind turbine to the extent of fall-off distance [Hub height of wind turbine + (½ * rotor diameter of wind turbine) + 5m] and the solar panels are proposed in the remaining area. After exclusion of fall-off distance area, we could find ample amount of land for the development of the proposed 1000 MW solar farm (assuming 1 MW of solar farm development will require 4 acres of land). Tentatively, 1000 MW solar PV plant with PV panel fixed tilt at 22^0 will consist of 80000 numbers of full Tables (strings) and the same can be accommodated at the site. The boundary earmarking the fall-off distance with the wind turbine models considered in the study (Model A & B) are shown in Figures 5.1 & 5.2 respectively.

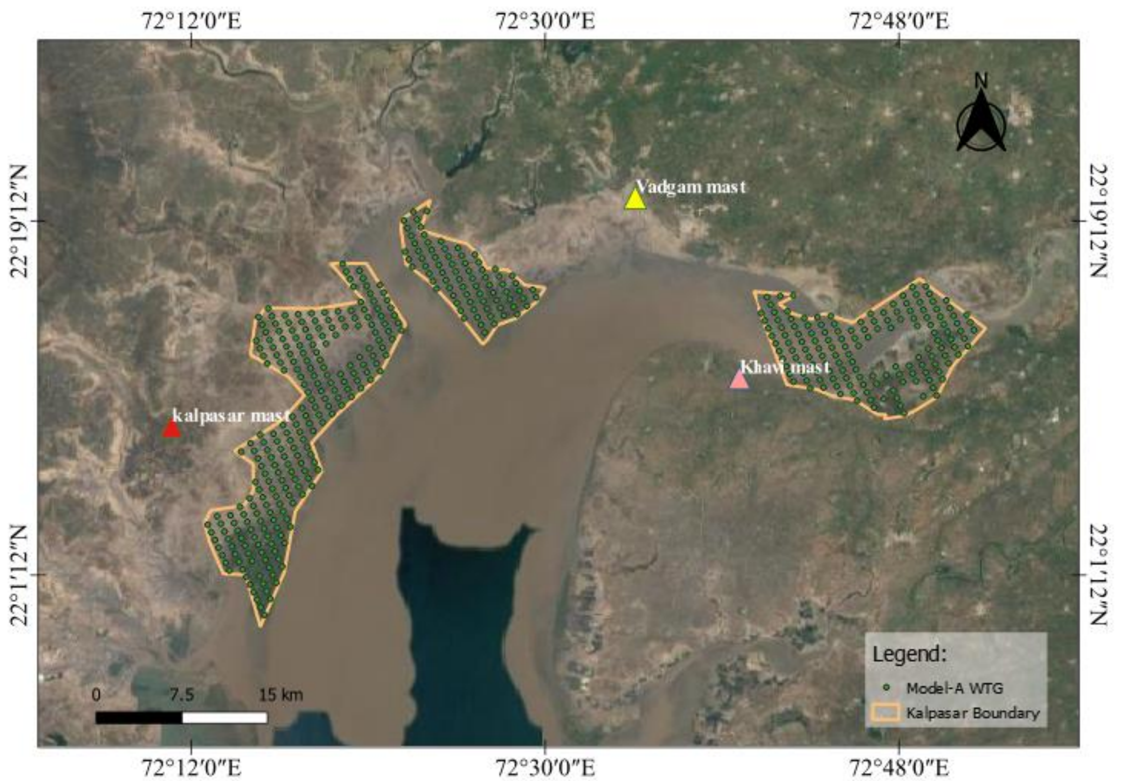


Figure 5.1: Plant Layout for Model A WTG

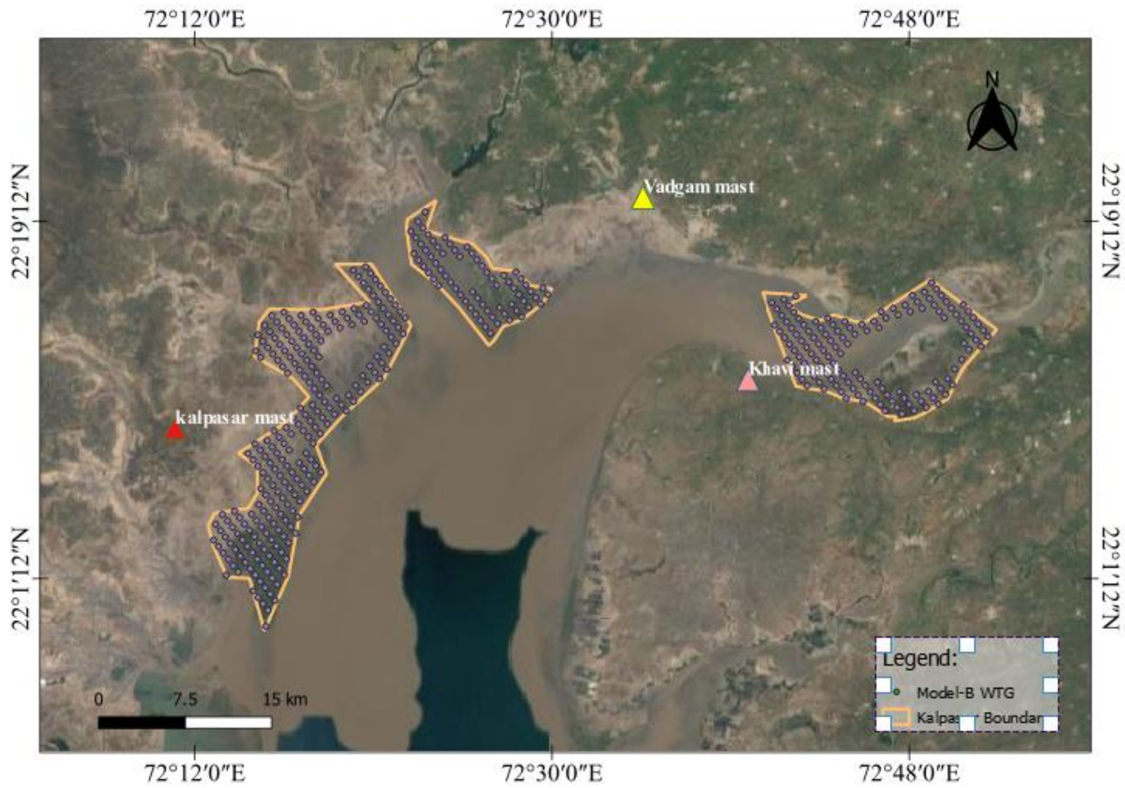


Figure 5.2: Plant Layout for Model B WTG

The PVSyst software was used for calculation of Solar % CUF for the region. NIWE's solar Atlas data was considered for meteo-data. Based on the calculation, the Performance Ratio of the region is 82.49%, which is shown in Table 5.1 and the CUF is estimated as 17.91%. The CUF estimation has been carried out based on 1:1 – DC: AC ratio assumption. The assumed module used for the calculation are mention below and the performance ratio of the region is shown in the Table 5.1.

Table 5.1: Summary of Solar components Parameters

Tilt/Azimuth			22°
PV module	**Unit Nom. Power**		500 Wp
	Number of PV modules		2000000 units
	Modules		80000Strings x 25 in series
		Nominal (STC)	1000000 kWp

	Total PV power	Total	2000000 modules
		Module area	4778496 m²
Inverter	Unit Nom. Power		4000 kWac
	Number of inverters		250 units
	Total power		1000000 kWac
	Operating voltage		802-1500 V
	Pnom ratio (DC:AC)		1.00
	Total inverter power	Total power	1000000 kWac
		No. of inverters	250 units
		Pnom ratio	1.00
Array losses	Array Soiling Losses (Loss Fraction)		3.0 %
	Module mismatch losses		1.0 % at MPP
	Strings Mismatch loss		0.1 %
	DC wiring losses		1.5 % at STC
	Series Diode Loss		0.1 % at STC
Produced Energy			1569 GWh/year
Perf. PR Ratio (Performance Ratio)			82.49 %
%CUF			17.91 %

5.2 Wind Energy

This chapter briefs about the wind flow modelling study and wind farm layout design carried out at Kalpasar dam site based on the long term corrected wind measurement & other inputs viz., contour (elevation) map and roughness (land cover) map. Energy estimation details are shown in Chapter 7.

5.2.1 Wind Flow Modelling using WAsP

Keeping into consideration the homogenous/flat terrain available at the proposed site, WAsP software (Version 12.8) was used for the wind flow modelling analysis in this study. In this regard, NIWE has prepared the contour map using the SRTM (Shuttle Radar Topography Mission) 1 arc data and the roughness map has been prepared using the satellite images. The results of the wind flow model developed using WAsP were further used to prepare the wind resource map and to carry out micrositing.

Wind Atlas Analysis and Application Program (WAsP) is an industry-standard software for wind resource assessment, Micrositing and energy yield calculation for wind turbines and wind farms. It is a PC- program developed by the Wind Energy and Atmospheric Physics Department, DTU, Denmark, for the vertical and horizontal extrapolation of wind data. WAsP is found to provide accountable results within its operating envelope (terrain with similar wind climatology – homogeneous terrain conditions), however the model has its own limitations. Wind Atlas prepared for Europe using WAsP indicates that the prediction may differ up to +/- 15% or more.

Since there is no significant obstacle offering shelter effect at the point of observation, no obstacle file was created for the flow modelling analysis. It was decided to design the wind farm in the area between 3m to 5m contour lines to effectively utilize the reclaimed land. Based on the wind flow modelling results, Micrositing was carried out for the following selected sites (3m-5m) at Kalpasar region.

The region of interest for the micrositing study is shown in Figure 5.3 below.

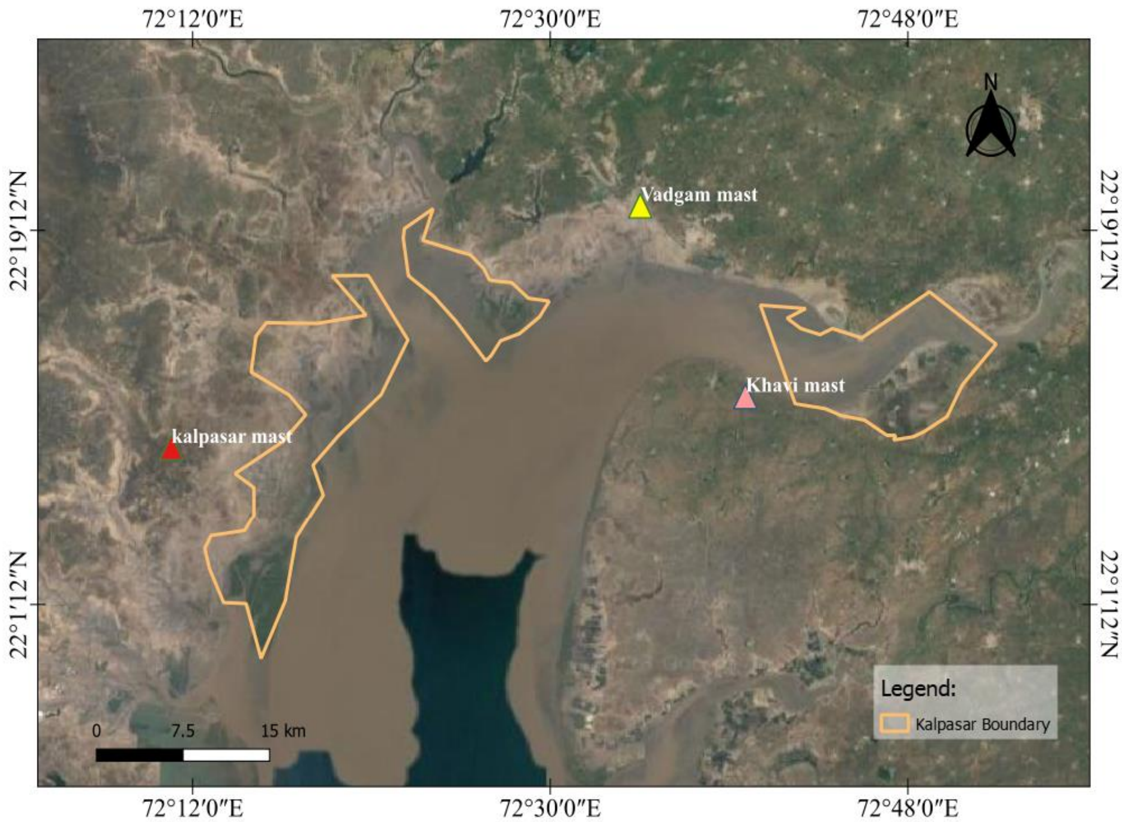


Figure 5.3: Boundary Layout

5.2.3 Wind Turbines used for the Study

Based on the wind regime and turbulence intensity results of the measurement region, the region of interest is found to be falling under IEC Class III C category. Considering the same, NIWE has carried out energy estimation analysis using the following two Wind Turbine models extracted from the latest RLMM (Revised List of Models and Manufacturers) list, wherein safety has been given high priority, as shown in Table 5.2.

Table 5.2: Wind Turbine Generator Models

S. No	Wind Turbine Generator	Capacity (MW)	Rotor diameter (m)	Hub height (m)	IEC Class
1	Model A	3.3	156	140	Class S
2	Model B	3.465	145	127.5	Class S

The wind turbines considered in this study are just to acquire some basic understanding and to act as a reference about the energy potential of the site and not for recommending any of the particular turbine or their manufacturers. Authenticated details have to be obtained from the manufacturer during the design/project execution phase. The power curve and thrust curve of the wind turbines considered in this study are accessed from public sources and the NIWE database. The standard power curves were corrected for the site-specific air density of the proposed turbine locations in lines with the IEC standard.

5.2.4 Wind farm Layout for different models

Based on the site investigation and wind flow modelling results, Micrositing was carried out for the selected sites within the Kalpasar dam premises. The Micrositing was carried out by giving importance to wake loss, minimum fall off distance from the nearby buildings, roads and the solar farm. In this layout, as it consists of multiple rows, a minimum of 5Dx7D distance in all the region was maintained between the turbines. The wind turbines have also been placed in the boundary of the land, to the maximum possible extent, without violating the standard Micrositing guidelines. The wake loss was also given high priority and the layout was developed in such a way that the average wake loss does not exceed 13%.

Model A

The enlarged view of model-A type wind turbine in the region is shown below in Figure 5.4.

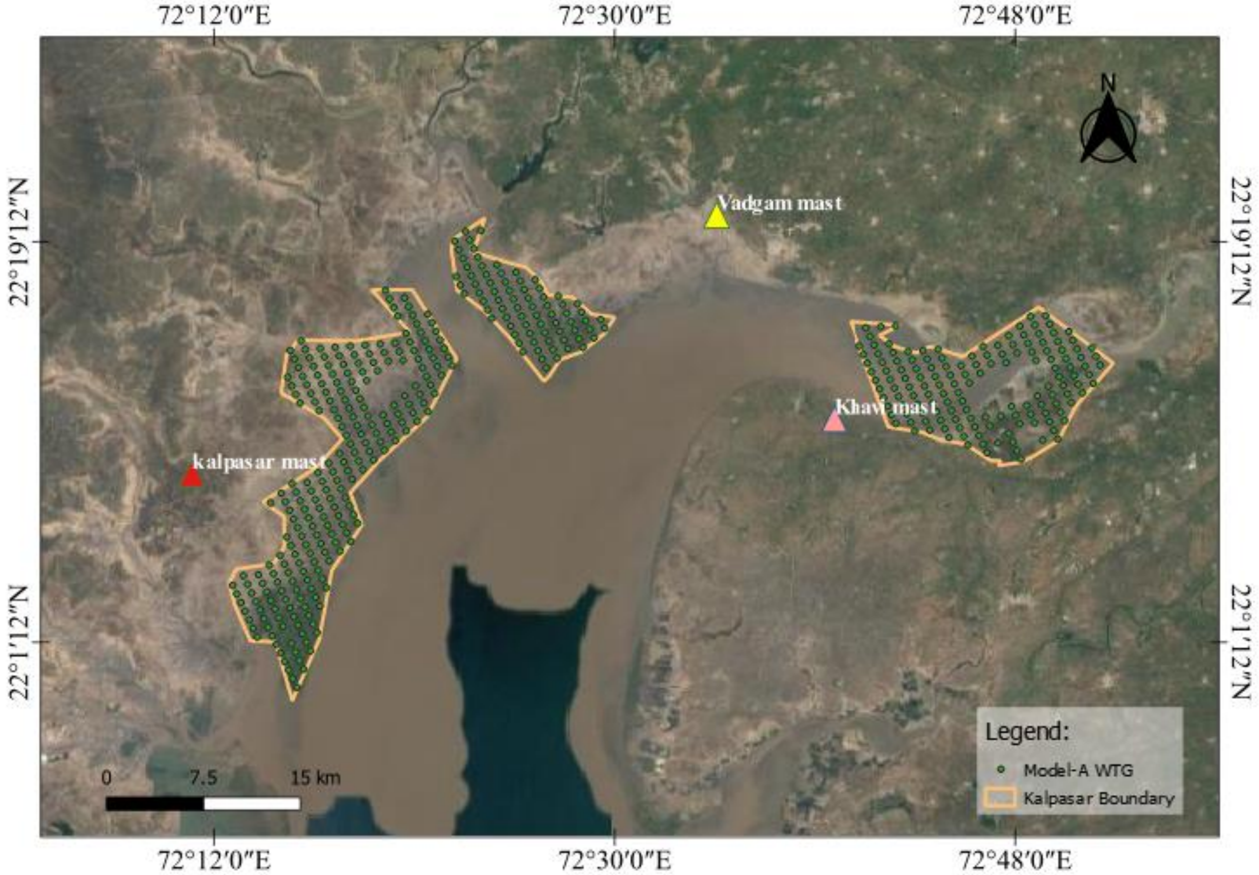


Figure 5.4: Micrositing Layout for Model A

Model B

The enlarged view of model-B type wind turbine in the region is shown below in Figure 5.5.

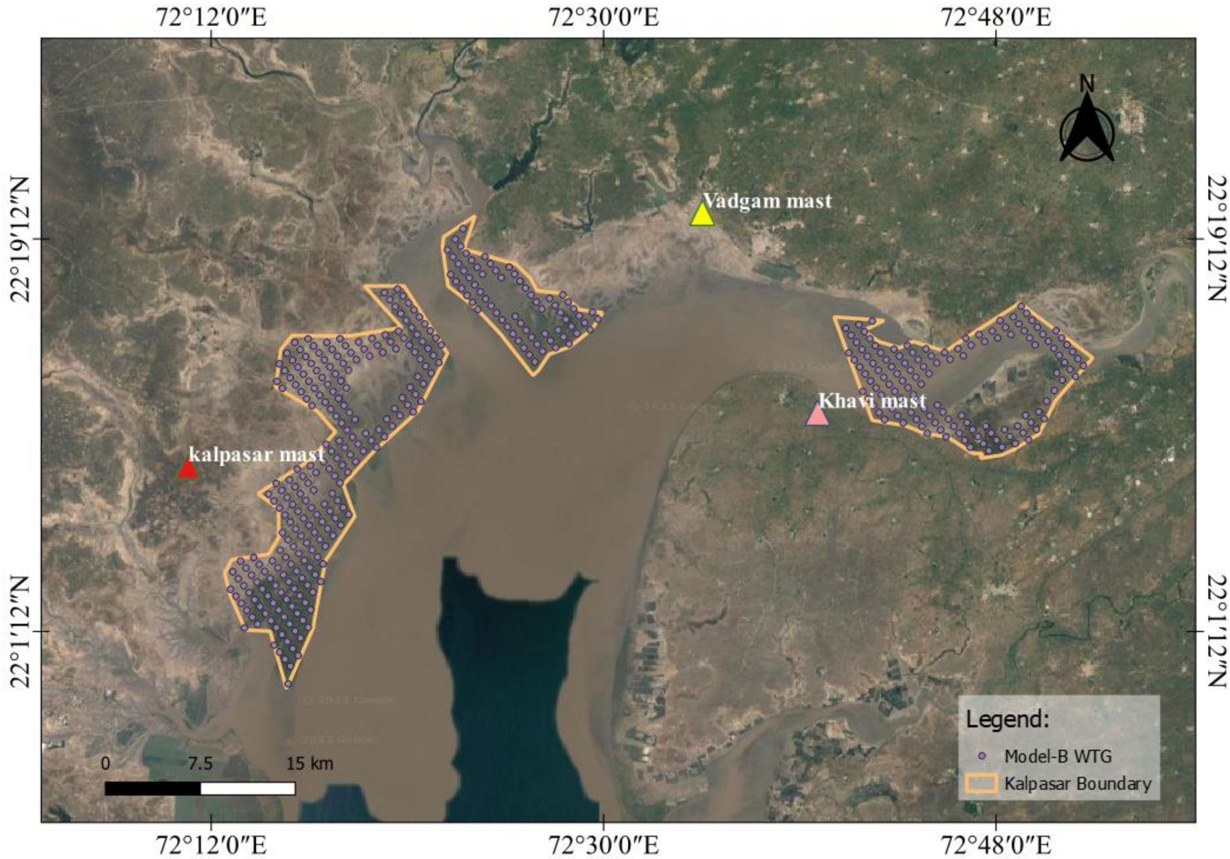


Figure 5.5: Micrositing Layout for Model B

The overall wind farm capacity details for different models is explained in Table 5.3.

Table 5.3: Wind farm capacity for each WTG models

WTG Model	Rated Capacity of WTG (MW)	No. of. Turbines	Wind farm capacity (MW)
Model A	3.3	455	1501.5
Model B	3.465	433	1500.3

6. RE INFRASTRUCTURE TECHNOLOGIES

6.1 Solar Energy

Solar PV power plant system comprises of C-Si (Crystalline Silicon)/ Thin Film Solar PV modules with intelligent Inverter having MPPT technology and Anti-Islanding feature and associated power electronics, which feeds generated AC power to the Grid. Other than PV Modules and Inverter/Inverters, the system consists of Module Mounting Structures, appropriate DC and AC Cables, Array Junction Boxes (AJB) / String Combiner Boxes (SCB), AC and DC Distribution Box, Lightning Arrester, Earthing Systems, meter, etc. The system should be capable for exporting the generated AC power to the Grid, whenever the Grid is available with all System Protection facilities.

6.1.1 SPV Modules

The SPV Modules must only the PV modules that are empanelled to the enlisted in ALMM list issued by MNRE. Solar photovoltaic modules with efficiency more than 18% for multi-crystalline, 20% for monocrystalline silicon.

6.1.2 Module Mounting Structure:

1. The structure design shall be appropriate and innovative. It must follow the existing land profile
2. The structure shall be designed to allow easy replacement of any module and shall been line with the site requirements.
3. As per the IS-875 (part 3)-1987 [code of practice for design loads (other than earthquake) for buildings and structure-wind loads], the structures will be designed to withstand the wind speed 170 km/hr.
4. Civil foundation design for Module Mounting Structures (MMS) as well as control room, equipment room and power equipment shall be made in accordance with the India Standard Codes and prevailing soil conditions.
5. MMS structure shall be hot dip galvanized with minimum thickness of 75 microns coating provided each side
6. The structure height considering highest flood level at the site. The minimum clearance between the lower edge of the module and the ground shall be the higher of (i) accessed highest flood level at the site and (ii) minimum of 750 mm

6.1.3 Power Conditioning Unit (PCU)

As the PV array performance varies with the solar radiation during the course of a day, the inverter MPPT extracts the maximum power possible by operating at Maximum Power Point. The inverter effectively acts as the interface between the PV output and the grid, and synchronizes the power output to the grid frequency and phase in order to minimize breakdown losses. The general technical requirements of the Power Conditioning unit as detailed in Table 6.1.

Table 6.1: Power Conditioning Unit parameters

Parameter	Specification
Rated AC power	As per design
Maximum input voltage	1000 V/ 1500 V
Rated AC output voltage	As per design
Tolerance on rated AC output voltage	+/- 10%
Rated frequency	50 Hz
Operating frequency range	As per CEA guidelines
Power factor control range	0.9 lag to 0.9 lead
efficiency Minimum	98%
Maximum loss in Sleep Mode	0.05% of rated AC power
Total Harmonic Distortion	Less than 3% at 100% load
Degree of protection	IP 54(Indoor)/IP 66 (Outdoor)
CEA Technical standards for connectivity to the grid regulations 2007 with 2013 Amendment, 2016 draft Amendment must be followed.	

6.1.4 Cables

The cables used in the solar PV plant shall be robust and able to resist high mechanical load and tension along with the UV rays of the Sun. Modules are equipped with attached junction boxes with 4mm^2 (modules connection inside the array), 8mm^2 (from string terminal to string combiner box) and 120/150mm^2 (From string combiner box to inverter DC terminal) coper cables and MC4 connectors and respective connectors according to cable dia. Modules will be interconnected, with these cables, in series as per design. Single core 4/8 mm^2 cable can be used to connect strings to String Monitoring Box (SMU). All IEC/IS standards must be complied while choosing the DC cables.

1. All cables and connectors for use for installation of solar field must be of solar grade which can withstand harsh environmental conditions including High temperatures, UV radiation, rain, humidity, dirt, salt, burial and attack by moss and microbes for 25 years and voltages as per latest IEC standards. (Note: DC cables for outdoor installations should comply with the TUV 2PfG 1169/09.07 for service life expectancy of 25 years)
2. The wiring for modules interconnection could be in the weather resistant pipe of repute make. All the buried cables can be run through HD pipe/ DWC conduit. However, for crossing with road, drain and trenches etc., the cable must pass through GI pipe of appropriate size.

6.1.5 Switchboard box / DC Distribution Box (DCDB) / AC Distribution Box (ACDB) panels

SMU incorporates the feature of paralleling strings to monitor current and voltage in each string through SCADA system on regular basis. This monitoring is useful to trigger maintenance alarm systems to identify short circuit or cable break situation. SMUs must have Reverse Blocking Diodes of maximum DC blocking voltage of 1000V, suitable arrangement for surge protection, through Surge protection device. The SMU shall have manufacturer verified compatibility with the inverter and must be equipped with appropriately sized string fuses. protected scheme must follow IEC 60269-6 (IEC 60269-6:2010 gives supplementary requirement to those given in IEC 60269-1 for fuse-links for protecting photovoltaic (PV) strings and photovoltaic (PV) arrays in equipment for circuits of nominal voltages up to 1500 V DC).

6.1.6 Transformer

Transformer shall be copper wound, 3 phase, natural cooled, core type construction, and oil immersed and shall be suitable for outdoor applications. Inverter duty transformers and auxiliary transformer shall comply with the latest/relevant IS/IEC standards meeting the norms.

6.1.7 HT Switchyard

1. The HT panel is an interface between the transformers and grid providing the switching, control and protection required for the electrical substation.

2. Circuit Breaker and Accessories: The circuit breaker and associated switchgears will be conforming to IS 10118/ IS 13118/IEC 60947 standards. The circuit breaker will be totally re-strike free under all duty conditions and will be capable of breaking magnetizing current of transformer and capacitive current of unloaded overhead lines without causing over voltages of abnormal magnitudes. HT panel shall consist of VCB and the associated C & R Panel for each PV quadrant. The switchgear will contain all equipment viz. Circuit breakers, CTs, PTs, relays and associated equipment.
3. Instrument transformer: Current transformer shall be provided as per IS 2705. Potential transformer shall be provided as per IS 3156. For purposes of measurement and protection adequate number of CTs and PTs have to be provided.
4. Isolators: Isolators will be complete with earth switch (wherever necessary), galvanized steel base provided with holes, solid core type post insulators with adequate creep age distance, blades made up of non-rusting material, operating mechanism (gang operated, manual/motor charging mechanism). They will be of centre post rotating horizontal double break type and consist of 3 poles.

6.1.8 Metering Bay

Metering is required to adhere to the state utility and CEA regulations. The metering arrangement should be compatible with the Availability-based-tariff (ABT) mechanism along with a check meter with Modbus arrangement and facility to provide remote monitoring. The meter would have web communication facility and should be visible at the State Load Dispatch Centre (SLDC). The meter shall conform in all respects including performance and testing thereof to the following Indian/ International Standards.

6.1.9 Earthing

There will be dedicated Earthing stations for DC Earthing for PV array panels and structures, Inverters, transformers and High voltage panels. Maintenance free earthing stations are preferable for the design to have long-term trouble-free performance in comparison to conventional pipe Earthing. All the modules shall be appropriately earthed in accordance to the IEC and IS standards. Grounding of the modules may be done as recommended by manufacturer. The earthing layout and number of earth pits required shall be calculated based on soil resistivity and design requirements.

All PV Modules, module mounting structures, and string monitoring unit structures in the PV array field shall be bonded to the earthing system by two distinct connections

6.1.10 Supervisory Control and Data Acquisition, SCADA

The entire solar PV power plant shall be integrated with SCADA system which should communicate with all the inverters and String Monitoring Unit (SMU) for displaying parameters mentioned below. The integrated SCADA shall have the feature to be used either locally via a local computer or also remotely via the Web using either a standard modem or a GSM / WIFI modem and broadband. SCADA shall have provision of tracking the status of breakers and relays. SCADA shall be confirming to IEC 60870.

6.1.11 Lightning & Over Voltage Protection

Detailed risk analysis shall be made to consider the requirement vis-a-vis obtaining insurance cover. The cost for providing full lightning protection should be compared with possible shadow losses that might occur due to the lightning arrestor mounting and fitment. Illustrative image of lightning arrestor is given in following Figure. Design requirement for lightning protection of PV system would be in conjunction with IEC 62305-2 or IEC 62305-3 or IS 2309, while taking into consideration the local weather information for determining the likelihood of thunder or lightning frequency. The site comprising of transformers, inverters, etc. shall be provided with adequate lightning protection. Similarly, the entire main control room building and four pole structure arrangement shall be protected from lightning strike with Lightning Conductor as per requirements of IS-2309 Standards. The earthing stations for the lightning discharges will be provided with test links of phosphorus bronze and located at 150 mm above ground level in an easily accessible position for testing. The LA is Level –II ESE type & has protection radius of 107Mtr at height of 7Mtr. Necessary concrete foundation for holding the lightning conductor in position will be made after giving due consideration to the maximum wind speed and maintenance requirement at site in future. Each lightning conductor shall be fitted with individual separate earth pit as per required Standards including accessories, and provided with masonry enclosure with cast iron cover plate having a locking arrangement, watering pipe using charcoal or coke and salt as per required provisions of IS.

6.1.12 Civil Works

Detailed soil investigation and contour survey at required location for the purposes of foundation design and other design/ planning required for the successful completion of the project.

6.1.13 Topographical survey

Topographical survey shall have to be done at site at 10m interval with the help of Total Station or any other suitable standard method of survey. All necessary Reduced Levels (RL) as entered in the Field Book have to be submitted along with pre contour layout of the total site. The formation levels of the proposed power plant have to be fixed with reference to High Flood Level of the proposed site. The ground level and plinth level of structures shall be fixed taking into consideration the highest flood level and surrounding ground profiles. The filled earth must be well compacted as per relevant IS standards.

6.1.14 Soil Tests

The detailed Geotechnical investigation to ascertain soil parameters of the proposed site for the use of planning / designing / construction / providing guarantee / warranty of all civil work including but not limited to foundations / piling for module mounting structures, HT lines, etc. The soil investigation should be done through any Govt. approved / certified soil consultant. All RCC works shall be provided of required grade of concrete as per relevant IS specifications as well as soil data considering appropriate earthquake seismic zone, wind velocity, weather effect, soil characteristics etc.

6.1.15 Soil Investigations

The scope of soil investigation covers execution of complete soil exploration including boring, drilling, collection of undisturbed soil samples where possible otherwise disturbed soil samples, conducting laboratory test

6.2 Wind Energy

The infrastructure constitutes a significant part of the overall wind farm project cost. The lack of understanding of ground conditions, weather conditions and difficulty to access are the major factor influencing the wind farm projects. The wind farm infrastructure consists of civil works, wind turbine & its components, electrical works and SCADA systems.

6.2.1. Wind Turbines

The wind turbines proposed to be installed at the site should have a valid type-certificate and shall be listed in the RLMM (Revised List of Models and Manufacturers) in vogue.

6.2.1.1 General Requirements:

- The type of WTG shall be of proven design, identical, commercially available and grid-connected type.
- The turbine shall be suitable to this site condition
- The WTG shall be fitted with components as specified in the Certificate.
- The WTG shall be complete with all parts and components necessary for normal operation during the lifetime of the WTG.
- All materials, components, and equipment shall be new, factory-made and designed to ensure easy maintenance and from approved manufacturers.
- A shelter erected near the tower (for Lattice tower) shall protect equipment installed at the tower base. In the case of the tubular tower, the equipment erected inside the tower base shall be protected suitably taking into consideration the environmental impact at the site.
- The WTG shall comply with CEA guidelines (in vogue) of Low Voltage Ride through (LVRT).

6.2.1.2 Main Design Criteria:

- The WTG must be suitable for continuous and satisfactory operation at the site for the prevailing wind and climatic conditions and designed to have a minimum of 20 years' operating life. If the life of any of the components is less than 20 years, such components shall be listed, stating the expected life.

- The blades should be designed based on a standard specification, which may be indicated bynumber, date of issue, issuing authority.
- The WTG shall have a minimum of two independent and fail-safe braking systems, of which at least one must be of the aerodynamic type.
- The WTG operation and safety shall be governed by a control and protection system. The protection system shall be activated whenever the WTG is not kept within normal operating limits due to Control System failure, effects of internal/external failure, or on account of any dangerous event.
- The Local Control System (LCS) of the WTG shall be based on a microprocessor having a facility for fiber optic cable/RF-based communication with Central Monitoring & Control Station (CMCS) with a facility for remote control and a centralized remote monitoring system for control and monitoring and database system including supply of a good configuration personal computer for monitoring along with Ethernet option for remoteaccess facility. In addition, details of the data logger for this purpose are to be furnished.
- Details of auxiliary power supply as required for various segments of Electrical and Automations system shall be furnished. Similarly, provision of cooling system for Electrical panels etc. shall be separately brought out in the offer.

6.2.1.3 Rotor:

The rotor shall be so manufactured as to be least affected by the tropical weather and coastal conditions at the site for itslife profile surface smoothness etc. The rotor should have its own aerodynamic brake so that extra torque due to strong wind, gust, storm, etc., is only marginally transmitted to the high-speed shaft of the gearbox if any. The blades shall be sturdy enough to maintain their shape andalignment when kept installed or stopped condition at any angle to the vertical and for a long period of time. The safety system of the rotor assembly shall be of fail-safe design. The blades of the rotor shall have inbuilt lightning protection. This will be in addition to lightningprotection provided for the rest of Nacelle's equipment.

6.2.1.4 Transmission:

The gearbox, if provided, shall be of proven and special design suitable for WTG application from an experienced and reputed manufacturer for long and trouble-free operation. Standard components shall be used to give high reliability. The gearbox, if used, shall be providedwith a temperature sensor mounted in the sump for measuring the oil temperature amongst other parameters. The transfer of vibrations from the gearbox to the nacelle shall be minimized & necessary provisions shall be made in accordance.

6.2.1.5 Braking System:

- Two independent braking systems shall be necessary, out of which one should be aerodynamic type through tip brake or pitch control.
- The aerodynamic brake may be hydraulic or mechanical or electrical type but shall be so designed that braking force shall be applied evenly through all the blades to avoid vibration and undue stresses on the rotor. The operation of the braking system shall be fool proof and shallhave a minimum adverse effect due to the ingress of dust and water/ moisture into the moving parts. In any case, these brakes shall have the facility of auto/ remote controlled resetting when activated. In case the hydraulic power pack is located in the hub, the unit shall be certified for operation at any position with respect to horizontal level and shall be unaffectedby the centrifugal force experienced during over speeding of the rotor. Safety precautions against loss of power in this braking system shall be incorporated.
- Fail-safe, heavy-duty electro-hydraulic or hydraulic brake shall be provided for mechanical braking of the rotor. This may be provided on high speed or low-speed shaft but not on the non-driving end of the generator to avoid fatigue-failure of the generator shaft. The brake shall be adequately rated to stop the rotor at full speed during sudden power failure. The Brake shoe line shall withstand temperature rise at the time of braking and have adequate surface area for dissipation of thermal energy. The shoes shall be capable of withstanding a large number of operations before requiring replacement.
- An additional brake manually operated from the nacelle shall be provided for holding the rotor in any position with the main brake(s) dismantled for inspection and

servicing.

6.2.1.6 Yaw System:

The WTG shall be provided with an active yaw system responding to the signals from the wind direction sensor. The yaw system shall possess a feature for automatic untwisting of cables connected to the Nacelle. The yaw system shall be protected against corrosion, dirt, and fatigue due to gusts, storm, freak wind-shift, etc.

6.2.1.7 Tower:

- The WTG shall have identical towers, either RCC or lattice or tubular or hybrid (a combination of lattice & tubular type) type fabricated from structural grade steel sections or plates or members and shall be galvanized or painted as specified. The tower shall be designed for the dynamic loading imposed by the normal operation of the WTG as well as to withstand survival wind speed without any damage. The permissible tolerances in the fabricationof towers shall be as per the relevant Indian standards.
- The towers shall be provided with facilities like convenient climbing devices etc., for safe access to the nacelle and to the aerodynamic brakes. Safety ropes, belts and necessary foundation bolts shall also be made available as & when required during erection time or during the O&M period.
- If tubular towers are offered, the local control panels and associated electrical equipment are installed inside the tower, a lockable door shall be provided at the base of the tower or insidethe tubular tower portion in case of hybrid towers. In the case of lattice-type or RCC tower, a separate electrical room with adequate protection against weather and unauthorized entry shallbe provided.

6.2.1.8 Generators:

The generators should be three-phase induction generators asynchronous/synchronous generators/Doubly-Fed Induction Generators (DFIG) /PMG (Permanent Magnet Generator) with Gear/Gearless compatible for 50 Hz grid connection, designed for tropical environment and in accordance with Indian / International standards applicable for design and manufacturing of generators which are also approved type by certifying agencies in their approved valid type certificates.

6.2.2 Cabling:

6.2.2.1 Cable type:

Two categories of cables shall be provided, one for stationary equipment and the other for movable equipment and components. Irrespective of utilization voltage and current rating, all cables shall have a copper conductor and requisite grade. The cables shall be adequately insulated for the voltage required and shall be suitably color-coded for the required service.

6.2.2.2 Cable end termination:

The cable ends shall be terminated with adequate size metallic double compression cable glands/PVC *glands*, and the glands shall be earthed at two locations. Suitable lock-type crimping lugs shall be used for cable end terminations. Where cables are raised from the ground, suitable PVC pipe guarding shall be provided for cable raising with the sealing of the guarding PVC pipe, including a suitable clamp.

6.2.3 Environmental Protection:

- The surfaces of wind turbine are exposed to various types of adverse conditions including: water attack, salinity in soil, wear from sand and other small particles, chemical attack. The polymers such as gelcoat or paint coating provides as much protection as possible.
- Degradation mechanism take place as a result of polymer backbone, depolymerisation, cross-linking, changes in the covalent bond system or changes in a side chain.
- All materials, components, and equipment shall function and work properly during the lifetime without deterioration due to the climatic condition at the site.
- All exposed steel parts of the WTG system must be protected against corrosion by suitable environmental protection. Wherever galvanization is required, same shall have a minimum thickness as required under the relevant Standards to meet the operational requirement at the proposed site.

- In order to protect the foundation structure against galvanic corrosion, a corrosion protection must be used. Coating can be classified into metallic and non-metallic coatings. Suitable coating must be implemented based on test results.

6.2.4 Grid Tie-up:

- The transformer and the WTG shall be interconnected by the underground cable of a suitablerating to match the output of WTG.
- The transformer shall be protected by an air break switch, horn gap fuse, and lightningarrester mounted on a two-pole structure.
- The transformer shall be tower mounted *or mounted* on a suitably designed plinth.
- The transformer area in each WTG shall be provided with fencing as per CEA / CEIG standard or state EB requirement.
- WTG shall be interconnected through overhead lines to evacuate generated power to the common EB HT/EHT sub-station through the step-up transformer to the grid as applicable to the site.

6.2.5 Civil works

As discussed above, the major influence on the economic success of a wind farm is the energy production, which is determined by the wind farm site, the wind farm layout, foundation infrastructure and the choice of wind turbine.

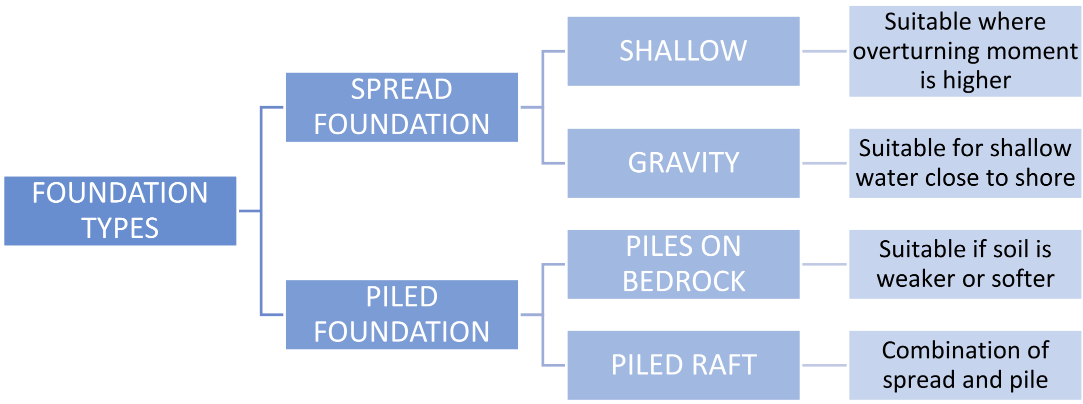
The disadvantage is that the environmental loadings on the larger structures lead to greater forces in the structure that would occur near shore in turn results in the civil-engineering problem. It is necessary to ensure that a sufficient connection with the ground is provided, otherwise the structure will get collapsed. A clear understanding of the load-transfer mechanisms, from foundation to the soil, leads to increased confidence in the overall design. It is critical to find that the foundation can sustain all loads, particularly during extreme environmental conditions.

The land near the shore is of very diverse materials, such as loose porous sand and the increased salinity level, so the type of foundation chosen should be of major concern in developing wind farm near shore at this site. Hence, a detailed site-specific foundation analysis has to be carried out based on the geo-technical bore hole study results at this site, as a part of detailed engineering.

The foundations shall be designed to take adequate care of the possible soil condition and adverse seismic effects on the basis of soil conditions of the site. For this purpose, it is required to carry out the soil investigation prior to the foundation work so as to establish the adequacy of tower and foundation design. The soil conditions, survival wind speed, load on tower and foundation, together with such other parameters required for a safe design of the tower and its foundation, shall be considered for the wind turbine selection & installation.

6.2.6 Foundation types

Many sustainable foundation types and methods are available for wind turbines on onshore. The foundation for on wind turbine towers (onshore) can be grouped into two types: (i) spread foundations and (ii) piled foundations.



Based on the loose and soft nature of the soil at the site, pile foundation is preferred with a diameter up to 6-8 meters. However, detailed geotechnical studies are essential to quantify the foundation requirements in a precise manner.

7. ENERGY ESTIMATION

7.1 Solar Energy

PV-Syst is used for simulating the solar energy yield estimations in this study. Initially, the design assumptions such as, technology, plant capacity, tilt angle, azimuth angle, plant layout, Solar PV modules, Inverters and associated loses in each components are collected, described and verified. Subsequently, the energy yield has been estimated for the first year and shown in the Table 7.1.The energy injection into the grid and the energy generation results from the PVSyst is shown in the Figures 7.1 and 7.2.

Figure 7.1: Energy Yield for First year

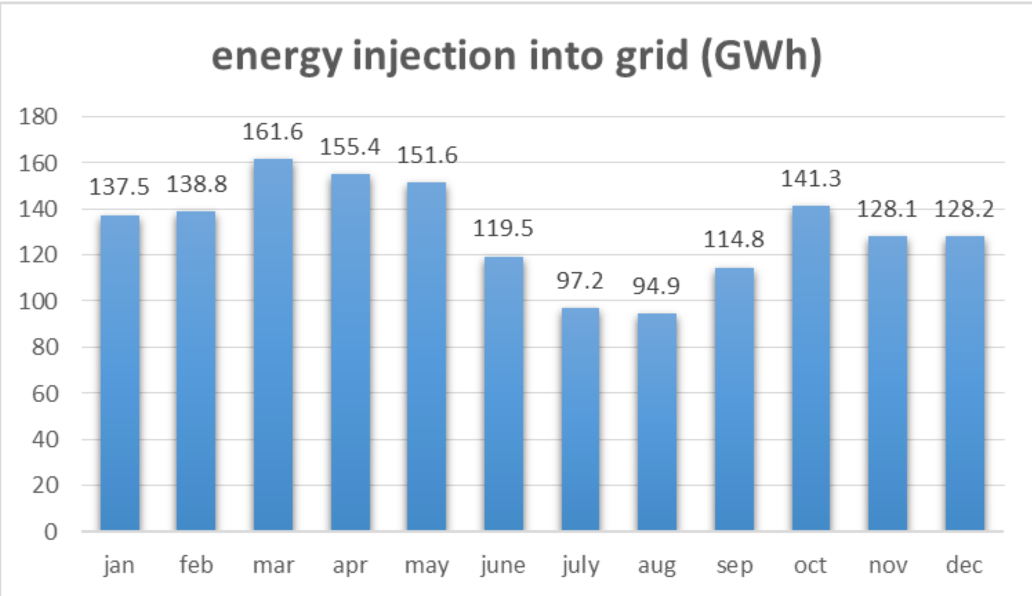


Table 7.1: Estimated Monthly Generation for 1000 MW

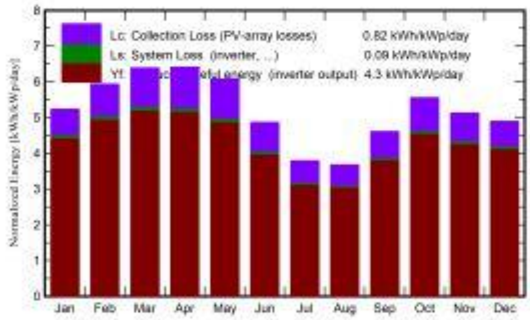
Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Energy Injection into Grid (GWh)	137.5	138.8	161.6	155.4	151.6	119.5	97.2	94.9	114.8	141.3	128.1	128.1

Main results

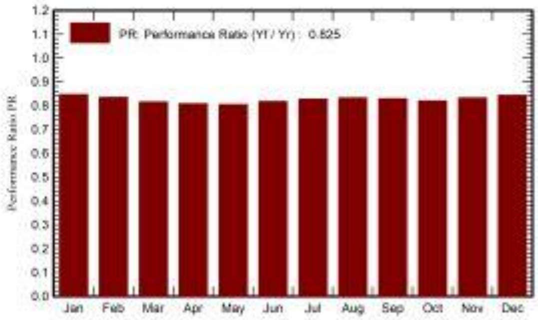
System Production

Produced Energy	1569 GWh/year	Specific production	1569 kWh/kWp/year
		Performance Ratio PR	82.49 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	125.7	43.50	20.78	162.4	154.9	140.4	137.5	0.847
February	137.8	44.20	23.46	166.3	158.8	141.8	138.8	0.835
March	179.8	57.30	28.14	198.1	188.9	165.1	161.6	0.816
April	191.3	65.50	30.90	192.4	182.9	158.6	155.4	0.808
May	201.3	77.80	32.80	188.5	178.8	154.7	151.6	0.804
June	158.9	87.40	31.16	146.2	138.3	121.9	119.5	0.818
July	125.2	91.50	29.13	117.5	110.9	99.1	97.2	0.827
August	118.0	86.90	28.20	114.0	107.5	96.7	94.9	0.832
September	133.1	74.10	28.32	138.4	131.4	117.1	114.8	0.829
October	149.1	58.10	29.14	172.3	163.9	144.1	141.3	0.820
November	122.6	46.10	25.58	153.9	146.8	130.8	128.1	0.832
December	116.1	42.50	22.08	151.9	145.0	130.8	128.2	0.844
Year	1758.9	774.90	27.49	1901.8	1808.2	1601.0	1568.9	0.825

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 7.2: PVSyst Energy generation report

7.1.1 Summary of Losses

As per the requirement of simulation model, the various loss factors considered are listed in the Table 7.2. The loss diagram and the probability distribution are shown in Figures 7.3 and 7.4 respectively.

Table 7.2: Summary of Loss Factors Considered For Simulations

Sl.No.	Loss	Description	% Loss
1	Shading	Two types of shading losses, Near shading and Inter array shading are considered	0
2	Module Temperature	The characteristics of a PV module are determined at standard temperature of 25°C. For every °C temperature rise above this, module efficiency reduces according to their temperature coefficient.	0.8
3	Soiling	Losses associated with dust, dirt or pollution on the module surface.	3
4	Module mismatch	Losses due to "mismatch" of modules voltage and current profile while forming array.	1
5	DC wiring resistance	The electrical resistance in wires between the power available at the modules and at the terminals of the array gives rise to ohmic losses (I^2R).	1
6	Inverter losses	The inverter losses include efficiency, and other losses due both to the power and voltage threshold and due to operation above nominal power and voltage. Inverters convert from DC into AC with a certain specified maximum efficiency. Depending on the inverter load, they will not always operate at maximum efficiency.	1.5
7	Downtime	Downtime depends on the grid availability, diagnostic response time, stock of spare equipment and the repair response time.	0
8	LID Loss	Loss of performances arising in the very first hours of exposition to the sun, with Crystalline modules.	2

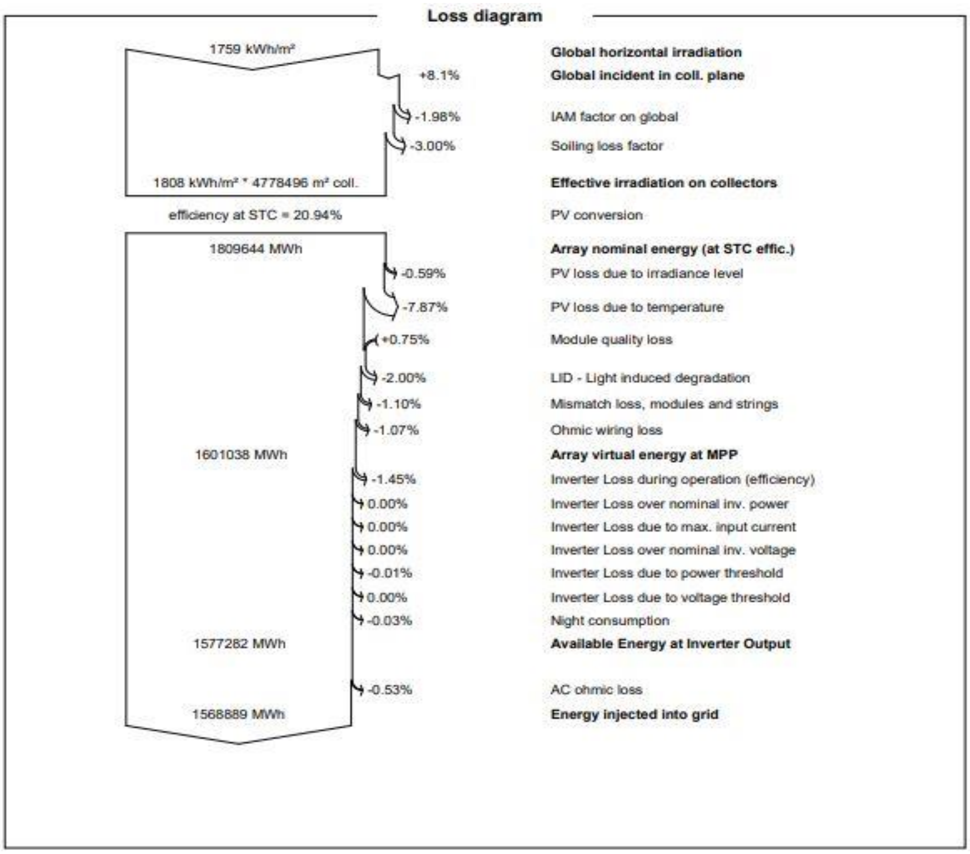


Figure 7.3: PVSyst loss diagram

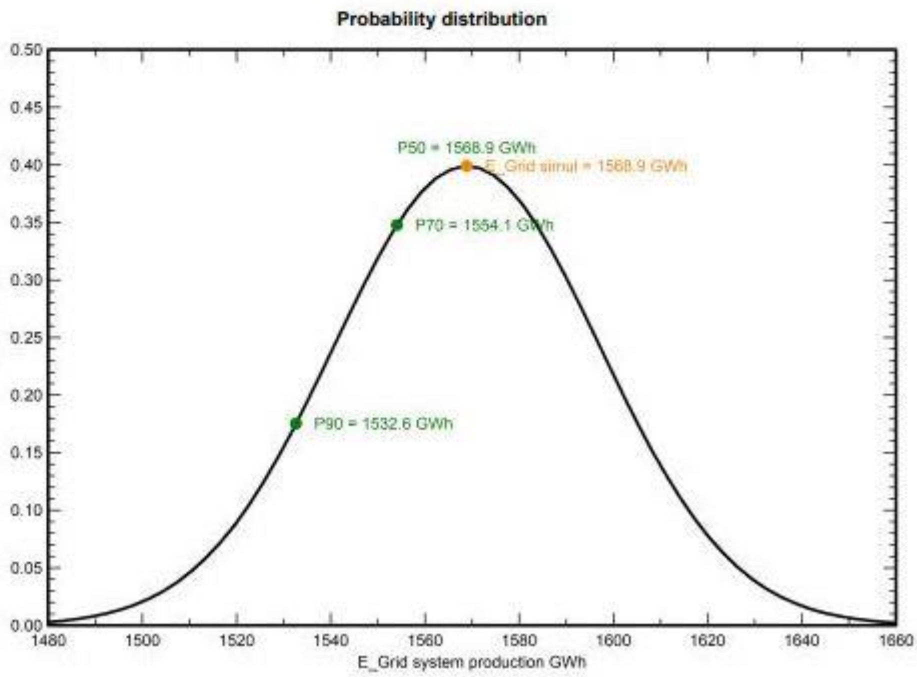


Figure 7.4: Probability distribution

7.1.2 Result

Based on the analysis it is found that solar farm capacity of upto 1000 MW can be installed at the site. The Annual Energy Production (AEP) and Capacity Utilization Factor (%CUF) of the proposed solar farm are given in the Table 7.3. These values may vary depending on the actual operating loss factors.

Table 7.3: Estimated AEP and %CUF for the respective solar farm models

Model	Area (acres)	Capacity (MW)	AEP (MWh)	CUF (%)
Model A	4000	1000	1569000	17.91

7.2 Wind Energy

Subsequent to the wind farm layout design, the energy yield from different wind turbine models has been estimated by placing them at the proposed locations. The energy yield has been estimated at different probability exceedance levels, in line with the industry practice, considering the standard loss factors and uncertainties as follows;

7.2.1 Loss Factor:

When wind energy estimations have been undertaken, different potential sources of energy loss viz., availability, turbine performance, electrical efficiency, environmental losses, curtailment losses, etc., must be considered. However, these losses are site-specific and exact value can vary significantly from project to project and from time to time; for example, some projects with poor transmission access may experience significant line outages or curtailment. Since the site-specific information is not available at this time, for this purpose, NIWE has assumed the standard loss factors such as Availability (Turbine & Grid), Electrical, Transmission loss etc. The actual values could be collected from the site during the operation of the wind farm. The loss factor summary is shown in Table 7.4.

Table 7.4: Loss Factor Summary

S. No	Summary	Loss factor assumption
1	**Future Wake Loss adjustment**	**98.00%**
2	**Availability**	**95.08%**
a	Turbine Availability	98.00%
b	Balance of Plant	99.00%
c	Grid Availability	98.00%
3	**Turbine Performance**	**99.00%**
a	High Wind Hysteresis	100%
b	Sub Optimal Performance	100%
c	Site Specific Adjustment	99%
4	**Electrical Efficiency**	**96.5%**
a	Operational Electrical Efficiency	97.00%
b	Wind Farm Consumption	99.50%
5	**Environmental**	**98.01%**
a	Rotor Blade Degradation	99.00%
b	High Temperature Shutdown	99.00%
c	Site Accessibility	100%
6	**Curtailment**	**100.00%**
a	Wind Sector Management	100%
b	Grid Curtailment	100%
c	Environmental Curtailment	100%
7	**Other Factors**	**100%**
Overall loss factor		**87.26%**

7.2.2 Uncertainty in the production estimate

The uncertainty analysis is an important part of any assessment of the long term energy production of a wind farm. The uncertainty of a production estimate is very dependent on the local wind climate, the topography, the data acquisition system, the period of data collection, the limitations of the software used for the estimation and power curve. To give an exact estimate of the uncertainty is not possible. Hence, NIWE has considered the standard uncertainties/assumptions while fixing up generation levels.

With regard to vertical extrapolation 0.3% uncertainty in wind speed has been assumed for 10m height variation between measurement and hub height of wind turbine. In addition, 1% additional uncertainty in considered for every 10m beyond the in case of Horizontal extrapolation, 0.5% uncertainty in wind speed has been assumed for every 1 km average distance of the wind farm from the mast.

The wind speed uncertainties have been converted into energy uncertainties through sensitivity analysis considering the sensitivity factor as **1.62** for Model A and **1.75** for Model B. The Uncertainty factors considered for the analysis for 1 Year, 10 Years and 20 Years of energy estimation are given in Table 7.5. The detailed uncertainties for Model A & Model B WTGs are shown in Table 7.5 to Table 7.10

Table 7.5: Uncertainties for the wind farm at Kalpasar site using Model A-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**6.72**		**6.72**		**6.72**
a	Calibration of Anemometer	1.00	1.62	1.00	1.62	1.00	1.62
b	Operational Characteristics of Anemometer	2.00	3.24	2.00	3.24	2.00	3.24
c	Flow distortion	3.50	5.66	3.50	5.66	3.50	5.66
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**5.35**		**3.94**		**3.84**
a	Inter Annual Variability	2.36	3.82	0.75	1.21	0.53	0.85
b	Wind in the past (MCP)	1.17	1.89	1.17	1.89	1.17	1.89
c	Long-Term Stability of Windiness	2	3.24	2	3.24	2	3.24
3	**Wind Flow Modelling**		**12.86**		**12.86**		**12.86**
a	Vertical	1.2	1.94	1.2	1.94	1.2	1.94
b	Horizontal	7.11	11.50	7.11	11.50	7.11	11.50
c	Wind Resource Similarity	1.5	2.43	1.5	2.43	1.5	2.43
d	Topographical Input Data	3	4.85	3	4.85	3	4.85
4	**Wind turbine power curve**	**2**	**3.24**	**2**	**3.24**	**2**	**3.24**
5	**Loss**		**0.57**		**0.57**		**0.57**
a	Wake		0.29		0.29		0.29
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
Overall Uncertainty in AEP (%)		**15.81**		**15.39**		**15.37**	

Table 7.6: Uncertainties for the wind farm at Vadgam site using Model A-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**7.28**		**7.28**		**7.28**
a	Calibration of Anemometer	2.00	3.24	2.00	3.24	2.00	3.24
b	Operational Characteristics of Anemometer	2.00	3.24	2.00	3.24	2.00	3.24
c	Flow distortion	3.50	5.66	3.50	5.66	3.50	5.66
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**5.49**		**4.30**		**4.23**
a	Inter Annual Variability	2.22	3.59	0.70	1.13	0.50	0.80
b	Wind in the past (MCP)	1.61	2.60	1.61	2.60	1.61	2.60
c	Long-Term Stability of Windiness	2	3.24	2	3.24	2	3.24
3	**Wind Flow Modelling**		**17.75**		**17.75**		**17.75**
a	Vertical	7.25	11.73	7.25	11.73	7.25	11.73
b	Horizontal	7.52	12.16	7.52	12.16	7.52	12.16
c	Wind Resource Similarity	1.5	2.43	1.5	2.43	1.5	2.43
d	Topographical Input Data	3	4.85	3	4.85	3	4.85
4	**Wind turbine power curve**	**2**	**3.24**	**2**	**3.24**	**2**	**3.24**
5	**Loss**		**0.57**		**0.57**		**0.57**
a	Wake		0.30		0.30		0.30
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
	Overall Uncertainty in AEP (%)	**20.22**		**19.93**		**19.92**	

Table 7.7: Uncertainties for the wind farm at Khavi site using Model A-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**6.72**		**6.72**		**6.72**
a	Calibration of Anemometer	1.00	1.62	1.00	1.62	1.00	1.62
b	Operational Characteristics of Anemometer	2.00	3.24	2.00	3.24	2.00	3.24
c	Flow distortion	3.50	5.66	3.50	5.66	3.50	5.66
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**4.89**		**3.71**		**3.63**
a	Inter Annual Variability	2.07	3.36	0.66	1.06	0.46	0.75
b	Wind in the past (MCP)	0.91	1.46	0.91	1.46	0.91	1.46
c	Long-Term Stability of Windiness	2	3.24	2	3.24	2	3.24
3	**Wind Flow Modelling**		**11.46**		**11.46**		**11.46**
a	Vertical	1.2	1.94	1.2	1.94	1.2	1.94
b	Horizontal	6.13	9.91	6.13	9.91	6.13	9.91
c	Wind Resource Similarity	1.5	2.43	1.5	2.43	1.5	2.43
d	Topographical Input Data	3	4.85	3	4.85	3	4.85
4	**Wind turbine power curve**	**2**	**3.24**	**2**	**3.24**	**2**	**3.24**
5	**Loss**		**0.57**		**0.57**		**0.57**
a	Wake		0.30		0.30		0.30
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
	Overall Uncertainty in AEP (%)	**14.53**		**14.18**		**14.16**	

Table 7.8: Uncertainties for the wind farm at Kalpasar site using Model B-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**7.27**		**7.27**		**7.27**
a	Calibration of Anemometer	1.00	1.75	1.00	1.75	1.00	1.75
b	Operational Characteristics of Anemometer	2.00	3.50	2.00	3.50	2.00	3.50
c	Flow distortion	3.50	6.13	3.50	6.13	3.50	6.13
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**5.79**		**4.26**		**4.16**
a	Inter Annual Variability	2.36	4.13	0.75	1.31	0.53	0.92
b	Wind in the past (MCP)	1.17	2.05	1.17	2.05	1.17	2.05
c	Long-Term Stability of Windiness	2	3.50	2	3.50	2	3.50
3	**Wind Flow Modelling**		**13.69**		**13.69**		**13.69**
a	Vertical	0.825	1.44	0.825	1.44	0.825	1.44
b	Horizontal	7.02	12.28	7.02	12.28	7.02	12.28
c	Wind Resource Similarity	1.5	2.63	1.5	2.63	1.5	2.63
d	Topographical Input Data	3	5.25	3	5.25	3	5.25
4	**Wind turbine power curve**	**2**	**3.50**	**2**	**3.50**	**2**	**3.50**
5	**Loss**		**0.57**		**0.57**		**0.57**
a	Wake		0.29		0.29		0.29
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
	Overall Uncertainty in AEP (%)	**16.92**		**16.46**		**16.43**	

Table 7.9: Uncertainties for the wind farm at Vadgam site using Model B-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**7.88**		**7.88**		**7.88**
a	Calibration of Anemometer	2.00	3.50	2.00	3.50	2.00	3.50
b	Operational Characteristics of Anemometer	2.00	3.50	2.00	3.50	2.00	3.50
c	Flow distortion	3.50	6.13	3.50	6.13	3.50	6.13
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**5.94**		**4.66**		**4.58**
a	Inter Annual Variability	2.22	3.88	0.70	1.23	0.50	0.87
b	Wind in the past (MCP)	1.61	2.82	1.61	2.82	1.61	2.82
c	Long-Term Stability of Windiness	2	3.50	2	3.50	2	3.50
3	**Wind Flow Modelling**		**19.05**		**19.05**		**19.05**
a	Vertical	6	10.50	6	10.50	6	10.50
b	Horizontal	8.44	14.77	8.44	14.77	8.44	14.77
c	Wind Resource Similarity	1.5	2.63	1.5	2.63	1.5	2.63
d	Topographical Input Data	3	5.25	3	5.25	3	5.25
4	**Wind turbine power curve**	**2**	**3.50**	**2**	**3.50**	**2**	**3.50**
5	**Loss**		**0.57**		**0.57**		**0.57**
a	Wake		0.30		0.30		0.30
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
	Overall Uncertainty in AEP (%)	**21.75**		**21.43**		**21.42**	

Table 7.10: Uncertainties for the wind farm at Khavi site using Model B-

S. No	Uncertainty Components	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)	Wind Speed (%)	Energy (%)
		1 year		10 years		20 years	
1	**Wind Measurement**		**7.27**		**7.27**		**7.27**
a	Calibration of Anemometer	1.00	1.75	1.00	1.75	1.00	1.75
b	Operational Characteristics of Anemometer	2.00	3.50	2.00	3.50	2.00	3.50
c	Flow distortion	3.50	6.13	3.50	6.13	3.50	6.13
d	Data Measurement Continuity	0.00	0.00	0.00	0.00	0.00	0.00
2	**Wind Variability**		**5.29**		**4.01**		**3.93**
a	Inter Annual Variability	2.07	3.63	0.66	1.15	0.46	0.81
b	Wind in the past (MCP)	0.91	1.58	0.91	1.58	0.91	1.58
c	Long-Term Stability of Windiness	2	3.50	2	3.50	2	3.50
3	**Wind Flow Modelling**		**11.91**		**11.91**		**11.91**
a	Vertical	0.825	1.44	0.825	1.44	0.825	1.44
b	Horizontal	5.86	10.26	5.86	10.26	5.86	10.26
c	Wind Resource Similarity	1.5	2.63	1.5	2.63	1.5	2.63
d	Topographical Input Data	3	5.25	3	5.25	3	5.25
4	**Wind turbine power curve**	**2**	**3.50**	**2**	**3.50**	**2**	**3.50**
5	**Loss**	**1.00**	**0.57**		**0.57**		**0.57**
a	Wake		0.29		0.29		0.29
b	Availability		0.24		0.24		0.24
c	Power Curve		0.25		0.25		0.25
d	Electrical		0.24		0.24		0.24
e	Environmental		0.25		0.25		0.25
f	Curtailment		0.00		0.00		0.00
	Overall Uncertainty in AEP (%)	**15.34**		**14.94**		**14.92**	

The summary of uncertainty values were prepared for Model A and Model B WTGs.

Table 7.11: Uncertainty Factors for different WTG Models in percentage

Mast	1 Year (%)	10 Years (%)	20 Years (%)
Model-A			
Vadgam	20.22	19.93	19.92
Khavi	14.53	14.18	14.16
Kalpasar	15.81	15.39	15.37
Model-B			
Vadgam	21.75	21.43	21.42
Khavi	15.34	14.94	14.92

Kalpasar	16.92	16.46	16.43

7.2.3 Results

The energy yield estimation results are shown in Table 7.12

Table 7.12: Estimated AEP & %CUF for the wind farm using different WTG models

Wind Turbine Models			
		Model A	**Model B**
Rated Capacity of the Turbine (MW)		3.3	3.465
Rotor Diameter (m) & Hub height (m)		156 & 140	145 & 127.5
Total number of Turbines		455	433
Wind Farm Capacity (MW)		1501.5	1500.3
Annual Cumulative Energy Generation (GWh) (Average for 20 Years)	**P50**	4823.04	4463.06
	P75	4229.74	3877.25
	P90	3695.75	3350.00
	P95	3376.18	3034.47
Capacity Utilization Factor (%)	**P50**	36.67	33.96
	P75	32.16	29.5
	P90	28.10	25.49
	P95	25.67	23.09

Based on the analysis, it is found that the wind farm can yield upto 28.10% CUF for Model-A & 25.49% CUF for Model-B at P90 probability exceedance level. However, it is to be noted that the generation & consumption profile are simulated results and derived based on the wind measurement and other inputs. However, the actual generation and consumption Figures may vary in the future depending upon various practical constraints and the year on year variation cannot be completely ruled out.

Further, in the present study the micrositing analysis has been carried out primarily based on wind potential and other standard micrositing guidelines such as wake loss limit, fall-off distance, etc. As the sites are in the coastline, the soil condition and Coastal Regulatory Zone (CRZ) clearance are expected to play a critical role in finalizing the wind turbine location at this site. Considering the same, it is insisted that the inputs from soil test and CRZ clearance have to be considered along with the technical points put up in this report during project execution.

8. POWER EVACUATION

8.1 Introduction

The scope of the Power evacuation study is to understand the challenges in expansion of the existing transmission system and the best operating condition of the existing system, based on load flow studies, contingency analysis and short circuit studies. The scope of the present study is the interconnection of 1500 MW wind farm and 1000 MW of solar photovoltaic system

8.2 Proposed Interconnection Scheme

The proposed wind solar hybrid system will be designed to meet the energy requirements of pumping stations which will be established in the Kalpasar dam area for irrigation purposes. The power generated from the wind and solar farm will have to be fed into the transmission system, which will can be utilized for irrigation purposes through an open access mechanism of the inter-state/ intra-state transmission system. The associated charges, wheeling and banking of power will have to be borne by the consumer, i.e the Kalpasar department as per the prevailing rates, declared by the CERC/ SERC.

The wind and solar farms will supply power to a dedicated pooling substation with a voltage of 220/33 kV or 400/33 kV, depending on the voltage level at which the Gujarat state transmission utility grants connectivity. According to the power evacuation study, the pooling sub-station will be connected to the grid sub-station at 400 kV or 220 kV. The Figure 8.1 below shows the transmission and wheeling mechanism of power from the wind solar farm to the irrigation pumps.

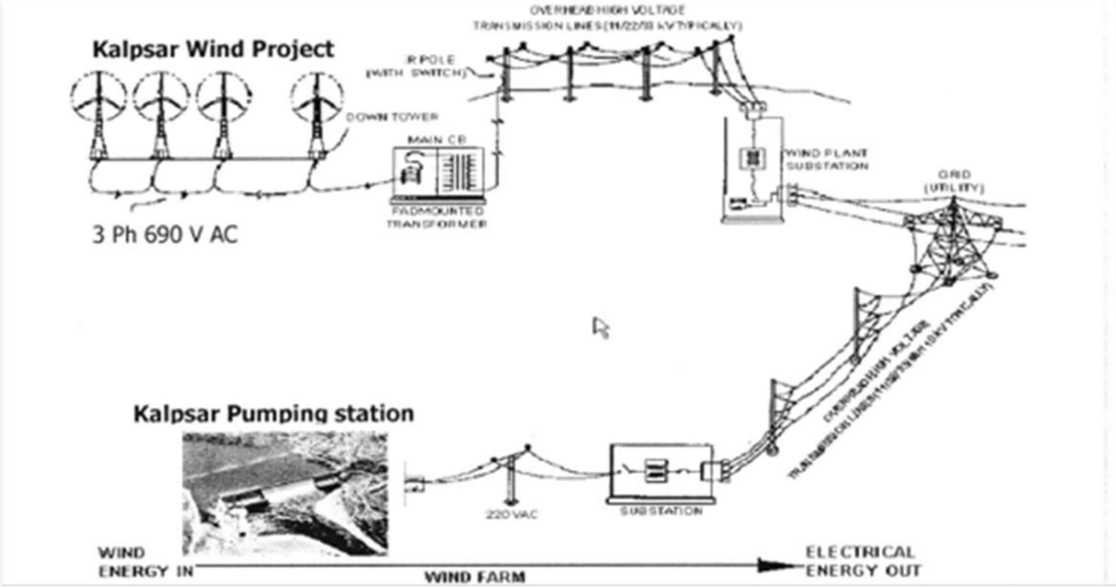


Figure 8.1: Schematic of power transmission from the wind solar farm to the pumping station

8.3 Inter-Connection To The Transmission Utility

Based on Literature review, PGCIL has carried out power system studies for grid strengthening and evacuation of approx. 15 GW power from Khavda potential RE zone in the northern part of Gujarat and 5 GW of power the Dholera Ultra Megawatt Solar project, by 2025. The proposed evacuation scheme is shown in Figure 8.2 below:

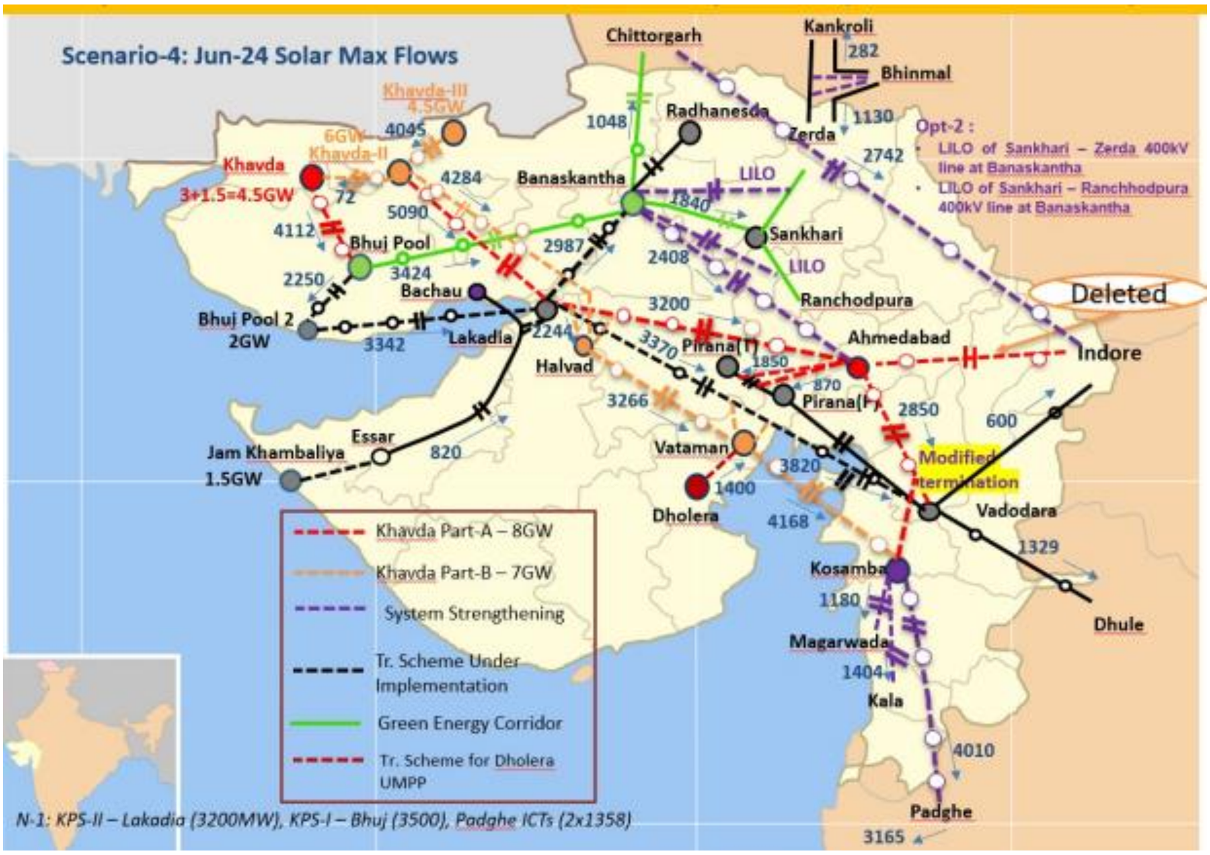


Figure 8.2: Proposed transmission corridor for evacuation of power from Gujarat RE zones (*Source: PGCIL*)

The proposed 765 kV transmission corridor from Khavda – Halvad- Vataman-Kosamba is one of the possible options for evacuating power from the Kalpasar wind-solar farm. The Dholera solar farm (near the Kalpasar project area) will be connected to the transmission corridor at the Vataman switching station as shown in Figure 8.3 below:

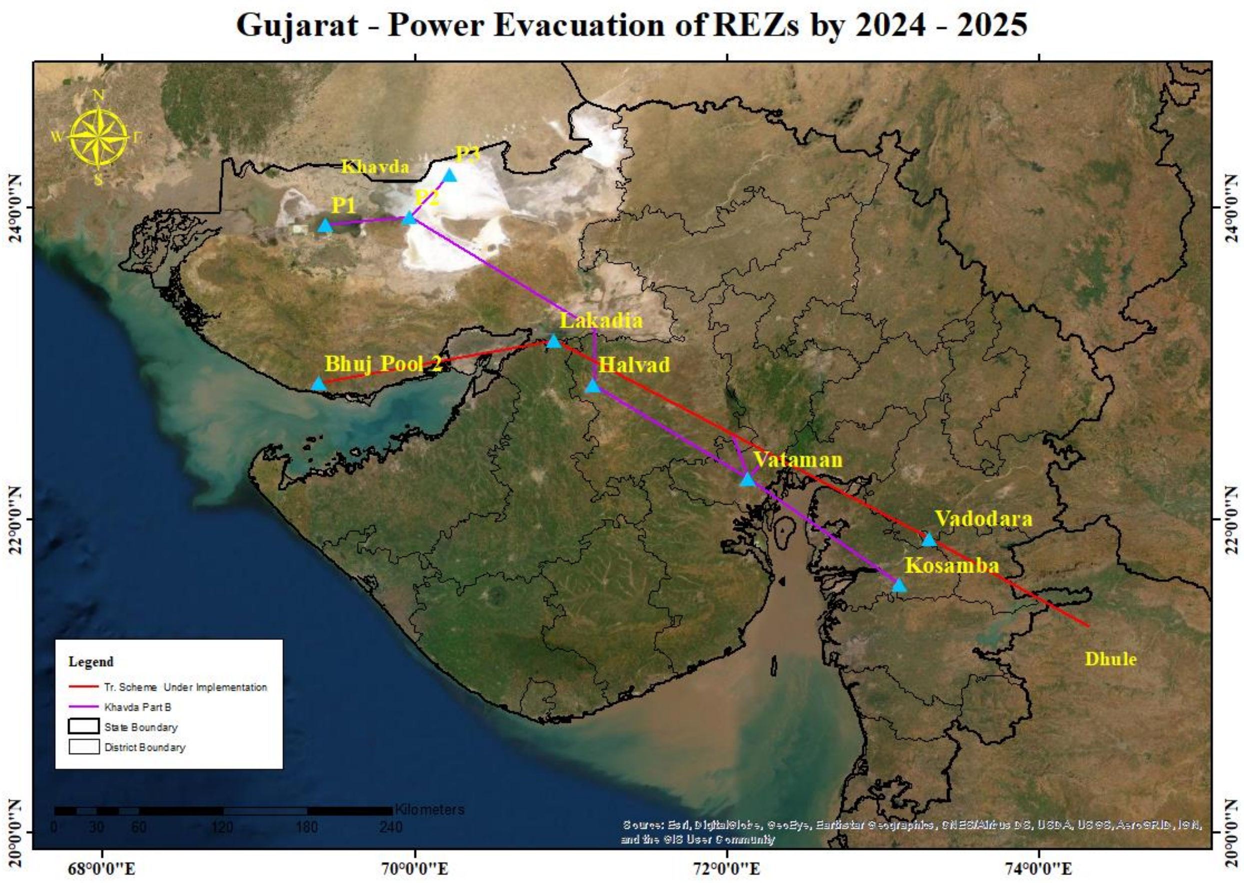


Figure 8.3: Possible interconnection scheme form the Kalpasar wind solar farm to the grid

The feasibility of the proposed evacuation scheme needs to be further analysed based on the generation details from the wind and solar farms and the load profile of the Kalpasar irrigation project, in consultation with GETCO.

9. FINANCIAL ASSESSMENT

9.1 Solar Energy

The indicative financial analysis for the solar farm development has been carried out in terms of estimating Levelized Cost of Energy (LCoE) by assuming the required Return on Equity. The details are as follows;

9.1.1 Assumptions

The indicative financial evaluation for the proposed solar farm is carried out by assuming 18% CUF. The assumptions of the financial components are shown in Table 9.1.

Table 9.1 – Indicative Financial Evaluation

Project Inputs			units
Project Cost	400.00		Lakhs
Debt Portion	70		%
Equity Portion	30		%
Debt Portion In Rs. Lakhs	280.00		Lakhs
Equity Portion In Rs. Lakhs	120.00		Lakhs
Repayment of Loan In Years	15		years
Interest Rate	8.00		%
Interest On Working Capital	8.00		%
Return On Equity (In %)	1yr To 10th yr	12	%
	11th yr To 25yr	12	%
	Avg ROE	12	%

Depreciation On Project Cost	4.67	%
O & M Expenses @ 2% Of Capex	8.00	Lakhs/MW
O & M Escalation Per Annum In %	3.84	%
Life Period	25	years
Depreciation	3% from 11th year onwards	%

9.1.2 Levelized Cost of Energy

As a result, Levelized Tariff for 25 Years (Rs/KWh) is estimated as **3.64 Rs/kWh** considering the huge size of the project, the project cost is considered as Rs.400 Lakhs/MW. With increasing cost for foundation, material selection and Operation & Maintenance the cost is expected to vary from the estimation.

9.1.3 Sensitivity Analysis

The LCoE indication under various scenarios developed with varying Project cost and %CUF is shown in the Table 9.2. The value is found to be varying between Rs. 2.69 to Rs. 4.26 per kWh.

Table 9.2 – Sensitivity Analysis for Project Cost and CUF

Project cost/CUF	17%	18%	20%	22%
5% increase in Project cost	4.06	3.84	3.45	3.14
10% increase in Project cost	4.26	4.02	3.62	3.29
5% decrease in Project cost	3.68	3.47	3.13	2.84
10% decrease in Project cost	3.48	3.29	2.96	2.69

9.2 Wind Energy

Based on the energy estimation analysis, NIWE has carried out an indicative financial evaluation for the development of 1500 MW wind farm in the Kalpasar dam region. The details are as follows;

9.2.1 Assumptions

Based on the energy estimation analysis, NIWE has carried out an indicative financial evaluation by assuming %CUF as 26.8% for wind farm. The components of the financial estimation are shown in the Table 9.3.

Table 9.3 – Indicative Financial Evaluation

Project Inputs			units
Project Cost	700.00		Lakhs
Debt Portion	70		%
Equity Portion	30		%
Debt Portion In Rs. Lakhs	490.00		Lakhs
Equity Portion In Rs. Lakhs	210.00		Lakhs
Repayment of Loan In Years	15		years
Interest Rate	8.00		%
Interest On Working Capital	8.00		%
Return On Equity (In %)	1yr To 10th yr	12	%
	11th yr To 25yr	12	%
	Avg ROE	12	%

Depreciation On Project Cost	4.67	%
O & M Expenses @ 1.5% Of Capex	10.50	Lakhs/MW
O & M Escalation Per Annum In %	3.84	%
Life Period	25	years
Depreciation	3% from 11th year onwards	%

9.2.2 Levelized Cost of Energy

As a result, Levelised Tariff for 25 Years (Rs./KWh) is estimated to be 4.07 Rs/kWh. Considering the size of the project and soil conditions, the project cost is assumed to be Rs.700 Lakhs / MW. In addition to this, the foundation cost has to be analysed in considering the type of foundation used in the region, since the region is near the coastal line.

9.2.3 Sensitivity Analysis

Considering the possibility of variation in project cost and estimated energy yield, the sensitivity analysis (LCOE) has been carried out by increasing and decreasing in the project cost with respect to CUF values, as shown in the Table 9.4. Based on the analysis, it is indicated that the LCoE value can vary between Rs. 3.27/ kWh in the best-case scenario to Rs. 4.99/ kWh in the worst-case scenario.

Table 9.4 – Sensitivity Analysis for Project Cost and CUF

Project cost/CUF	24%	26%	28%	30%
5% increase in Project cost	4.77	4.40	4.09	3.81
10% increase in Project cost	4.99	4.61	4.28	4.00
5% decrease in Project cost	4.31	3.98	3.70	3.45
10% decrease in Project cost	4.09	3.77	3.50	3.27

10. BENEFITS OF THE PROJECT

With the development of this project, numerous benefits can be accrued at the Kalpasar dam project, which includes.

1. Wind and solar energy generation can meet the dam's power demand. As a result, the irrigation process and overall rural development can be facilitated.
2. A wind energy project with a capacity of 1500 MW has been proposed for the land. Furthermore, a 1000 MW Solar PV power project is proposed for the land beneath and near wind turbines, resulting in a non-polluting green dam.
3. Altogether, the proposed wind-solar farm can generate approx. 5091.85 GWh / year
4. Approx. 4675 Kilo-tonne CO2 emission can be avoided (0.85kg CO2 for 1 kWh) per year
5. Environmental imbalance is avoided as a result of the reduction of climate change and other environmental pollution, which helps India meet its target of 500 GW of renewable energy by 2030.
6. The cost per kWh is competitive with rising costs for conventional power projects. It serves as a hedge against the price volatility of fossil fuels, ensuring energy security and preventing conflict over natural resources.

11. APPLICABLE STANDARDS

11.1 Indian Standards

11.1.1 Solar Energy

- **IS 14286:** Crystalline silicon terrestrial photovoltaic (PV) modules — design qualification and type approval.
- **IS-875 (part 3)-1987** [code of practice for design loads (other than earth quake) for buildings and structure-wind loads]
- **IS 16221 (Part 1):** 2016 -Safety of Power Converters for use in Photovoltaic Power Systems Part 1- General Requirements
- **IS 16221 (Part 2):2015 -** Safety of Power Converters for Use in Photovoltaic Power Systems Part 2- Particular Requirements for Inverters
- **IS 16169: 2014-** Test Procedure of Islanding Prevention Measures for Utility-Interconnected Photovoltaic Inverters
- **IS 1554 -** XLP insulated grade

- **IS 7098-1 -**Cross linked polyethylene insulated PVC sheathed cables, Part 1:For Working voltage up to and including 1100 V
- **IS 7098-2 -**Cross linked polyethylene insulated thermoplastics sheathed cables Part 2: for working voltages from 3.3 kV up to and including 33 kV
- **IS: 2026,IEC 60076 -** Specifications for Power/inverter Transformer
- **IS: 2099 -** Bushings for alternating voltage above 1000 V
- **IS: 3639 -** Fittings and accessories for power transformer
- **IS: 9921 Part 1 to 5 -** Alternating currents dis connectors (isolators) and Earthing switches rating, design, construction, tests etc.
- **IS: 2705 Part 1 to 4 & IEC: 185 -** Current transformer
- **IS: 3156 Part 1 to 4 -** Voltage Transformer
- **IS: 3070 part 1 to 3 -** Lightning arrestors
- **IS: 2544 -** Porcelain insulators for system above 1000 V
- **IS: 5350 Part III -** post insulator units for systems greater than 1000V
- **IS: 5621 -** Hollow Insulators for use in electrical equipment
- **IS: 5556 -** Serrated lock washers specification
- **IS:12063 -** Degree of protection provided by enclosures
- **IS 10118/ IS 13118/IEC 60947** - Current transformer
- **IS 2705 -** Current transformer
- **IS 3156 -** Potential transformer
- **IS 3231 & IEC 255 -** All Electrical relays for power system protection
- **IEC 61850 -** protection, metering and monitoring
- **IS/IEC 62271-1 -** High Voltage Switchgear and Control gear - Part 1: Common
- **IS/IEC 62271-1-** High Voltage Switchgear and Control gear - Part 1: Common Specifications
- **IS/IEC 62271-100** - High Voltage Switchgear and Control gear - Part 100: AC Circuit Breakers
- **IS/IEC 62271-102 -** High Voltage Switchgear and Control gear - Part 102: AC Disconnector and Earthing Switches
- **IS/IEC 62271-200 -** High Voltage Switchgear and Control gear - Part 200: AC Metal Enclosed Switchgear and Control gear for Rated Voltages Above 1 kV and Up to and Including 52 kV
- **IEC 61869 -** Instrument Transformers
- **IS 3231-**Electrical relays for power systems protection
- **IS 9431-** Indoor post insulators of organic material for systems with nominal voltages greater than 1000 V up to and including 300 kV
- **IS 3070-3**- Lightning Arresters for Alternating Current Systems - Part 3 : Metal Oxide Lightning Arresters Without Gaps
- **IS 14697** - Class 0.2S and 0.2S AC Static Transformer Operated Watthour and Var-hour Meters,

- **ISS: 14697/1999 Reaffirmed 2004. -**AC static transformer operated watt-hour and VAR Hour meters, class 0.2 s.
- **IS: 2705-1992-** Specification for current transformers.
- **IS: 3156-1992-** Specification for voltage transformers.
- **IS: 5621-1980 -**Specification for Hollow insulators and accessories
- **IS: 2099-1986** -Specification for insulators/ bushing
- **IS: 3347-1986-** Specification for the dimension of Porcelain transformer
- **IS: 335-1983-** Specification for new insulating oil
- **IS 3043** -Code of practice for Earthing

11.1.2 Wind Energy

- **IS 16589 (Part 4) : 2017 IEC 61400 : Part 4 IEC 61400 : Part 4** - Wind turbines Part 4 design requirements for wind turbine gearboxes
- **IS 16589 (Part 11) : 2018 IEC61400-11 : 2012 IEC61400-11 : 2012** - Wind Turbines Part 11 Acoustic Noise Measurement Techniques
- **IS/IEC 61400-2 : 2013 IEC 61400-2:2013** - Wind Turbines Part 2 Small Wind Turbines
- **IS/IEC 61400-12-1) : 2017 IEC61400 -12-1: 2017** - Wind Energy Generation Systems Part 12 Electricity Producing Wind Turbines Section 1 Power performance measurements
- **IS/IEC/TS 61400-13 : 2015 IEC 61400 : Part 13 IEC 61400 : Part 13** - WIND TURBINES PART 13 MEASUREMENT OF MECHANICAL LOADS.
- **IS/IEC 61400-21 : 2008 IEC 61400 : Part 21 : 2008** - Wind turbines Part 21 measurement and assessment of power quality characteristics of grid connected wind turbines
- **IS/IEC 61400-22 : 2010 IEC 61400-22 : 2010 IEC 61400-22 : 2010** - Wind Turbines Part 22 Conformity Testing and Certification.
- **IS/IEC 61400-23 : 2014 61400-23:2014 61400-23:2014** - Wind Turbines Part 23 Full-Scale Structural Testing of Rotor Blades.
- **IS/IEC 61400-24 : 2010 IEC 61400 : Part 24 : 2010** - Wind turbines Part 24 lightning protection.
- **IS/IEC 61400-25-1) : 2017 IEC61400-25-1:2017** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 1 Overall description of principles and models.
- **IS/IEC 61400-25-2) : 2015 IEC 61400-25-2:2015** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 2 Information model.
- **IS/IEC 61400-25-3) : 2015 IEC 61400-25-3:2015** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 3 Information exchange models.

- **IS/IEC 61400-25-4) : 2016 IEC61400-25-4:2016** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 4 Mapping to communication profile.
- **IS/IEC 61400-25-5) : 2017 IEC 61400-25-5:2017** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 5 Compliance testing.
- **IS/IEC 61400-25-6) : 2016 IEC61400-25-6:2016** - Wind Turbines Part 25 Communications for Monitoring and Control of Wind Power Plants Section 6 Logical node classes and data classes for condition monitoring.
- **IS 61400 (Part 25/Sec 71) : 2019 IECTS 61400-25-71**: - Wind energy generation systems - Part 25-71 Communications for monitoring and control of wind power plants - Configuration description language.

11.2 Other Relevant Standards

11.1.1 Solar Energy

- **IEC 61215 / IEC 61646: c-Si (IEC 61215):** Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval Thin Film (IEC 61646): Design, Qualification & Type Approval
- **IEC 61730-1:** Photovoltaic Module safety qualification- Part 1: Requirements for construction
- **IEC 61730-2 :** Photovoltaic Module safety qualification- Part 2: Requirements for testing
- **IEC 61701 :** Salt mist corrosion testing of photovoltaic modules Tech Specs of On-Grid PV Power Plants 5
- **IEC 62716 :** Test Sequences useful to determine the resistance of PV Modules to Ammonia (NH3)
- **IEC 61683 Ed.1 -** Photovoltaic Systems – Power Conditioners – Procedure for Measuring Efficiency
- **IEC 61727** - Photovoltaic (PV) Systems Characteristics of the Utility Interface
- **IEC 62109-1 Ed.1 -** Safety of power converters for use in Photovoltaic Power Systems- Part 1: General Requirements
- **IEC 62109-2 Ed.1 -** Safety of power converters for use in Photovoltaic Power Systems- Part 2: Particular Requirements For Inverter
- **IEC 61000-6-2 Ed.2 -** Electromagnetic Compatibility (EMC)- Part 6-2: Generic Standard – Immunity Standard For Industrial Environments
- **IEC 61000-6-4 Ed.2.1 -** Electromagnetic Compatibility (EMC)- Part 6-4: Generic Standard – Emission Standard For Industrial Environments

- **IEC 60068-2-1:2007 -** Environmental testing - Part 2-1: Tests - Test A: Cold
- **IEC 60068-2-2:2007-** Environmental testing - Part 2-2: Tests - Test B: Dry heat
- **IEC 60068-2 14:2009-** Environmental testing - Part 2-14: Tests - Test N: Change of temperature
- **IEC 60068-2-30:2005 -** Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)
- **IEC 60189 -** test and measuring the methods
- **TÜV 2 PfG 1169/08.2007/ IS 7098 Part I -** DC cables for outdoor installations
- **IEC 60269-6** (IEC 60269-6:2010) - protected
- **IEC 60269-1** - fuse-links for protecting photovoltaic (PV) strings
- **IEC 60529 -** Enclosure Ingress Protection (IP rating level)
- **IEC 62262 -**Enclosure Impact Protection
- **IEC 60269-1,** IEC 60269-6 - Fuse
- **IEC 61643-12** Surge Protection Device
- **IEC 62852 -** Solar cable connector
- **IEC: 60076 (Part 1 to 5) -** Specifications for Power Transformer
- **IEC 60255 -**Measuring relays and protection equipment
- **IEC 61850 -**Communication networks and systems for power utility automation
- **IEC 61131-3** -Programmable controllers - Part 3: Programming languages IS 9385 High voltage fuses
- **IEC 60099-4** -Surge arresters - Part 4: Metal-oxide surge arresters without gaps for A.C. systems
- **IEC 62052-11 -** Part 11: Electricity metering equipment (A.C.) - General requirements, tests and test conditions Metering equipment
- **IEC 62053** -Electricity metering equipment (A.C.) - Particular requirements
- **CBIP publication No 304, July 2008.** -Manual on Standardization of Ac static electrical energy meters
- **IEC 62052-11-Electricity metering equipment (AC)** – General requirements, tests and test conditions
- **IEC 62053-22-**Static meters for active energy (class 0.2 s)
- **IEC 62056-**The standard for Electricity metering – Data exchange for meter reading, tariff and load control.
- **IEEE 80 IEEE -** Guide for Safety in AC Substation Grounding
- **IEEE 142 -**IEEE Recommended Practice for Grounding of Industrial and Commercial power systems

11.1.2 Wind Energy

- **INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC**), Wind Turbines – Part 1: Design requirements, Edition 3.0.

- **INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC),** Wind Turbines – Part 12-1: Power Performance measurement of electricity producing wind turbines, Edition 2.0.
- **MEASNET**, Anemometer Calibration Procedure, Version 3, September 2022
- **TECHNICAL GUIDELINES FOR WIND TURBINES**, Part-6: Determination of Wind Potential and Energy Yields, Revision 11
- **ISO/IEC GUIDE 98-3:2008**, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement, 2008

12. RECOMMENDATION

Based on the analysis the following are recommended for the successful development and operation of the wind & solar farm at the Kalpasar site;

1. The site seems to have promising wind and solar potential for development of large wind & solar farms to the tune of 1500MW & 100,0MW respectively. However, the site conditions, especially soil conditions and the corrosive environment prevailing at the site are expected to play a critical role in the design and lifetime of the wind and solar farms. Hence, detailed studies need to be carried out to understand these factors, and design needs to be evolved with appropriate mitigations.
2. With regard to Vadgam site, the wind measurement is only available at 50m height. In order to match up with the hub height of the wind turbines considered under this study, the 50m data had to be extrapolated upto 140m and 127.5m, which is a violation as per the MEASNET guidelines vertical extrapolation procedure. Such extrapolation may induce higher uncertainty into the analysis. Hence, it is recommend to install higher heights (atleast 100m) met. mast at the Vadgam region so as to enhance the accuracy of the prediction.
3. The geotechnical investigations and survey works have to be carried out to initiate the detailed design work for the construction of the foundation. Wind turbine foundation on soft or loose ground can experience poor load bearing capacity. Hence, it must be identified prior to construction and must be improved with deep foundation systems, if needed.
4. Corrosive study of the steel tower of the wind turbine in the soil near shore may help us to conclude the type of material and coating required.
5. The loose nature of the soil in the near shore region causes dust accumulation on blade surface, which affects the performance of the wind turbine. Hence, proper O&M activities

should be carried out. With respect to Solar panels, the impact of soiling is expected to be significant in this area and hence proper O&M strategies for regular cleaning of the panels should be devised, as a part of detailed engineering itself.

6. The RE integration to the grid makes the grid weak. Hence, a proper reactive power compensation methodology must be required to maintain the power factor within limits. The power from dedicated pooling substation must be connected to the Gujarat state transmission utility in which the grid strengthening is required for the evacuation of power.
7. At the pooling sub-station transformer capacity must be at least 1.5 times the total plant capacity and standby transformer is essential in case of failure.

13. SUMMARY

13.1 Introduction - Renewable energy

Renewable energy sources such as wind, solar, and other forms of solar energy have become the preferred option due to environmental concerns and rapidly depleting fossil fuel reserves. It is projected that India has a renewable energy potential of around 1500 GW, with solar power accounting for 750 GW (assuming that 3% of the country's land is used for solar installations) and wind accounting for 302 GW (at 100-m mast height) and 695 GW (at 120-m mast height), respectively. Small hydro and bioenergy have 20 GW and 25 GW potential, respectively. The Indian government has set a target of 175 GW by 2022. The objective is to generate 60 GW of wind energy, 100 GW of solar energy, 10 GW of biomass energy, and 5 GW of small hydro energy. Rooftop solar is expected to account for 40 GW of the 100 GW total, with the remaining 60 GW coming from ground-mounted, grid-connected medium and large solar installations. The Indian government recently set a target of 500 GW of renewable energy by 2030.

In order to explore the possibilities of Renewable energy, the National Centre for Coastal Research (NCCR), Chennai, has approached the National Institute of Wind Energy (NIWE) to prepare a Detailed Project Report to develop a wind-solar hybrid system around the Kalpasar Dam Project in order to maximize the use of natural resources. An important goal of this project is to explore the possibility of generating electricity from renewable sources such as wind and solar to meet the demand for electricity required to pump water from the dam and deliver it into canals.

The proposed land area near and below the wind turbine will be ideal for installing solar panel arrays. In order to pump irrigation water from the GKDP reservoir, a 1500MW wind farm and 1000 MW solar park has been proposed. Approximately 4000 to 4500 hectares of land will be required for this hybrid project.

13.2 Wind energy

The proposed feasibility study site for the wind-solar hybrid plant is in the Kalpasar site, as shown in Figure 13.1, which stretches along the Gulf of Khambhat from Bhavnagar to Bharuch district in Gujarat, in the western part of India. The designated RE area (also referred to as the "Boundary") is a homogeneous coastal land area of 430.6 sq.km that has been specifically designated for Renewable Energy-related projects. Based on three existing NIWE met mast sites in Gujarat, namely Kalpasar, Vadgam, and Khavi the analysis has been carried out. In order to cover up the entire wind farm area, as a part of the proposal, one number of 100m masts was proposed to be installed at the site. The geographical information of the met masts at Khavi, Vadgam sites, as well as the newly installed mast, are presented in Table 13.1, and the wind characteristics of the Kalpasar, Vadgam and Khavi sites are shown in Tables 13.2, 13.3 and 13.4.

Table 13.1. Location Details of the mast

Met Mast Name	Geographical coordinates							
	N(m)	E(m)	Elev. (m) ASL	Height of Mast (m)	Mean Wind speed (m/s)	WPD (W/m^2)	Turbulence Intensity (TI)	Year of data
Khavi	22°11'14.60"	72°39'59.50"	29	100	5.913	204.17	0.099	Jan 2015-Dec 2015
Vadgam	22°20'52.33"	72°23'46.64"	10	50	5.925	200.27	-	Aug 2006-July 2007
Kalpasar	22°8'47.26"	72°10'57.61"	7	100	6.245	237.19	0.077	July 2022 –June 2023

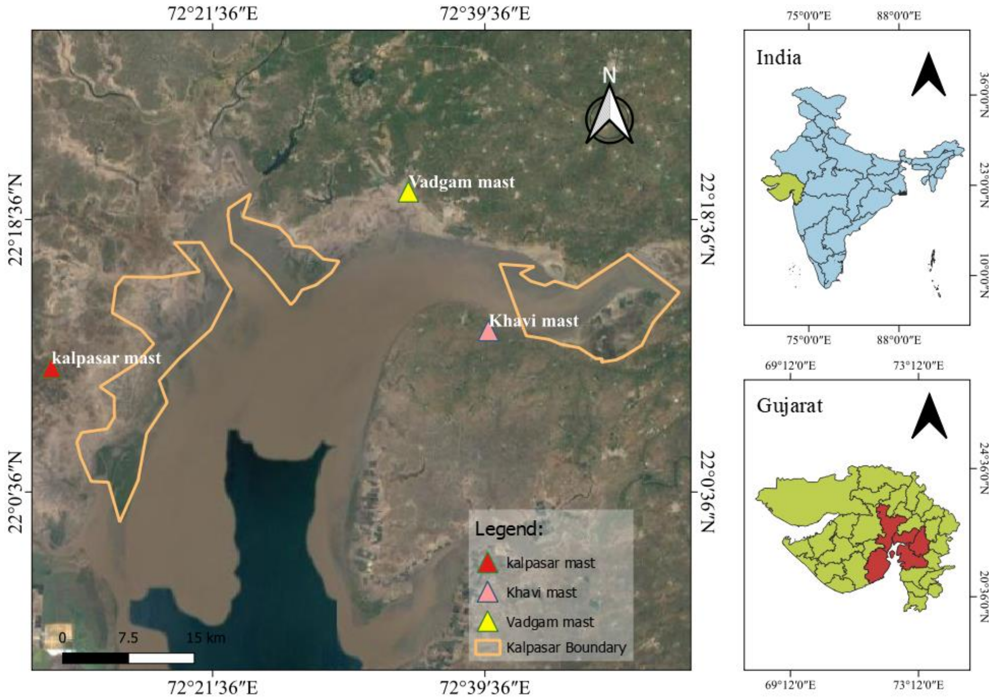
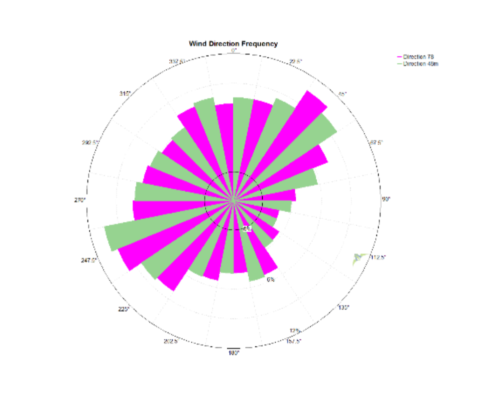


Figure 13.1: The Region of Interest

13.2.1 Wind Characteristic Details

Table 13.2 Wind Characteristics of Kalpasar Mast

Site Name/mast height	**Kalpasar / 100 m Height**
Period of Data taken for Analysis	July 2022-June 2023
Site Air density	1.162 kg/m^3
Annual mean wind speed 1^{st} Jan 2015 – 31^{st} Dec 2015 (100 Combined, 80 m, 50 m, 10 m)	6.425 m/s@ 100m Combined AGL, 5.932 m/s@ 80m AGL, 5.383 m/s@ 50m AGL, 3.912 m/s@ 10m AGL.
The predominant wind direction at the site	West of South west&North East & North of north west



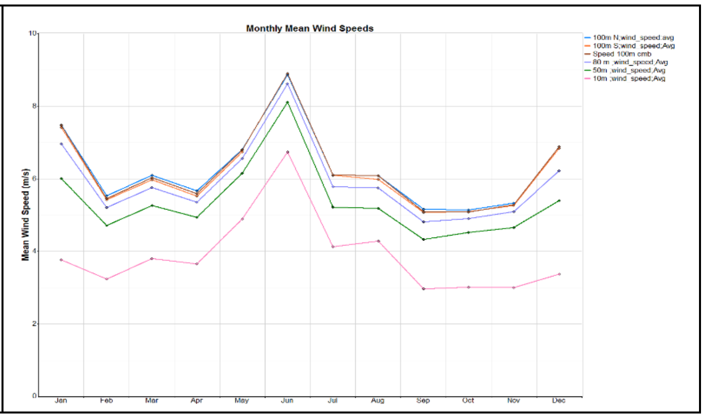


Table 13.3 Wind Characteristics of Vadgam Mast

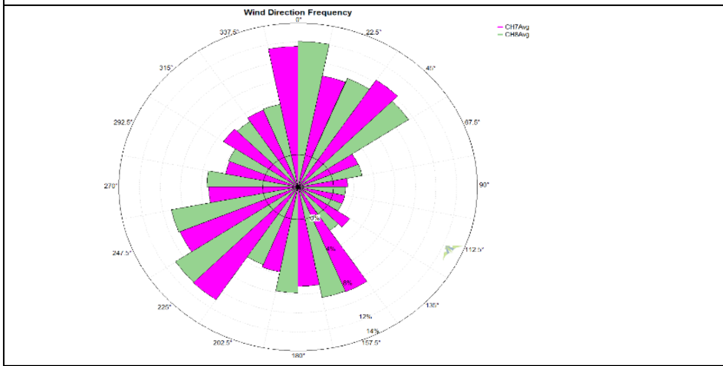
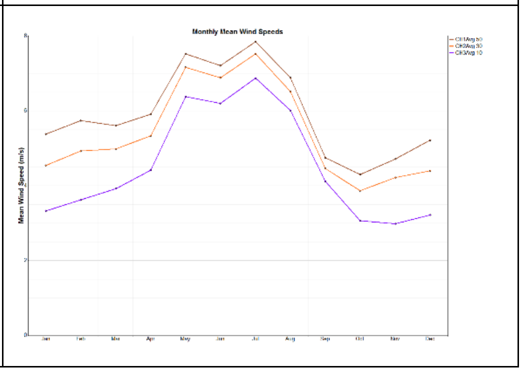
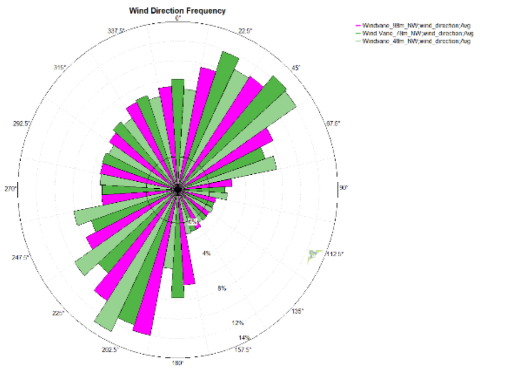
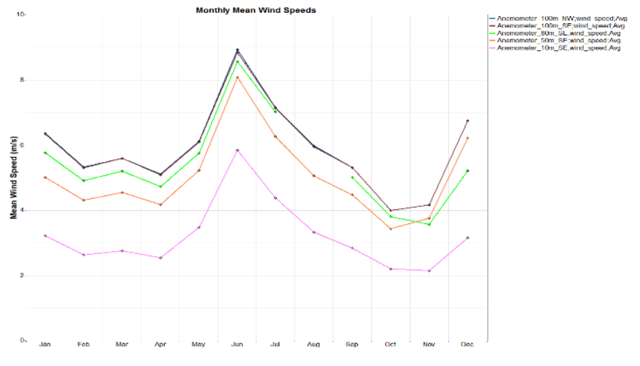
Site Name/mast height	**Vadgam / 50 m Height**
Period of data taken for analysis	1st Aug 2006 – 31st Jul 2007
Site Air density	1.217 kg/m^3
Annual mean wind speed July 2008 - July 2009 (50 m, 30m, 10 m)	5.925 m/s @ 50 m AGL 5.405 m/s @ 30 m AGL, 4.518 m/s @ 10 m AGL.
The predominant wind direction at the site	North - East, South - West
	

Table 13.4 Wind Characteristics of Khavi Mast

Site Name/mast height	**Khavi / 100m Height**
Period of data taken for analysis	January 2014 – December 2014
Site Air density	1.163 kg/m^3
Power law	0.259
Annual mean wind speed January 2015 – December 2015 (100m)	5.913 m/s @ 100m AGL, 5.370 m/s @80m AGL, 5.065 m/s @ 50m AGL, 3.226 m/s @ 10m AGL.

The predominant wind direction at the site.	South of South west & North East
	

The wind measurement at the site was conducted for one year, whereas the wind farm's operational period is 20 years. As a result, understanding the long-term variation of wind characteristics with the help of available data sources is critical in order to reduce uncertainty in estimation and mitigate the risk of underperformance of the wind farm. In this regard, ERA5 reanalysis data were used in the current study to perform long-term corrections for each region. WAsP software (Version 12.7) was used for this study's wind flow modelling analysis, considering the homogeneous/flat terrain available at the proposed site. In this regard, NIWE created the contour map using SRTM (Shuttle Radar Topography Mission) 1 arc data, and the roughness map was created using satellite images. The results of the wind flow model created with WAsP were then used to create a wind resource map and perform Micrositing.

13.2.2 Wind Turbines used for the study

Based on the wind regime and turbulence intensity results of the measurement region, the region of interest is found to be falling under the IEC Class III C category. Considering the same, NIWE has carried out energy estimation analysis using the following Wind Turbine models extracted from the latest RLMM (Revised List of Models and Manufacturers) list.

Wind Turbine Generator Models

S. No	Wind Turbine Generator	Capacity (MW)	Rotor diameter (m)	Hub height (m)	IEC Class
1	Model A	3.3	156	140	Class S
2	Model B	3.465	145	127.5	Class S

13.2.3 Micro siting and Estimation of Annual Energy Production (AEP)

Based on the discussion with NCCR, the elevation range between 3m to 5m contour line has been considered for the Micrositing layout preparation. Micrositing with 5Dx7D configuration is used to design the 1500 MW capacity wind farm. The uncertainty analysis is a critical component of any assessment of a wind farm's long-term energy production. As a result, when determining generation levels, NIWE considered the standard uncertainties/assumptions. The micro siting layout for Model A and Model B is shown in the Figure 13.2 & 13.3.

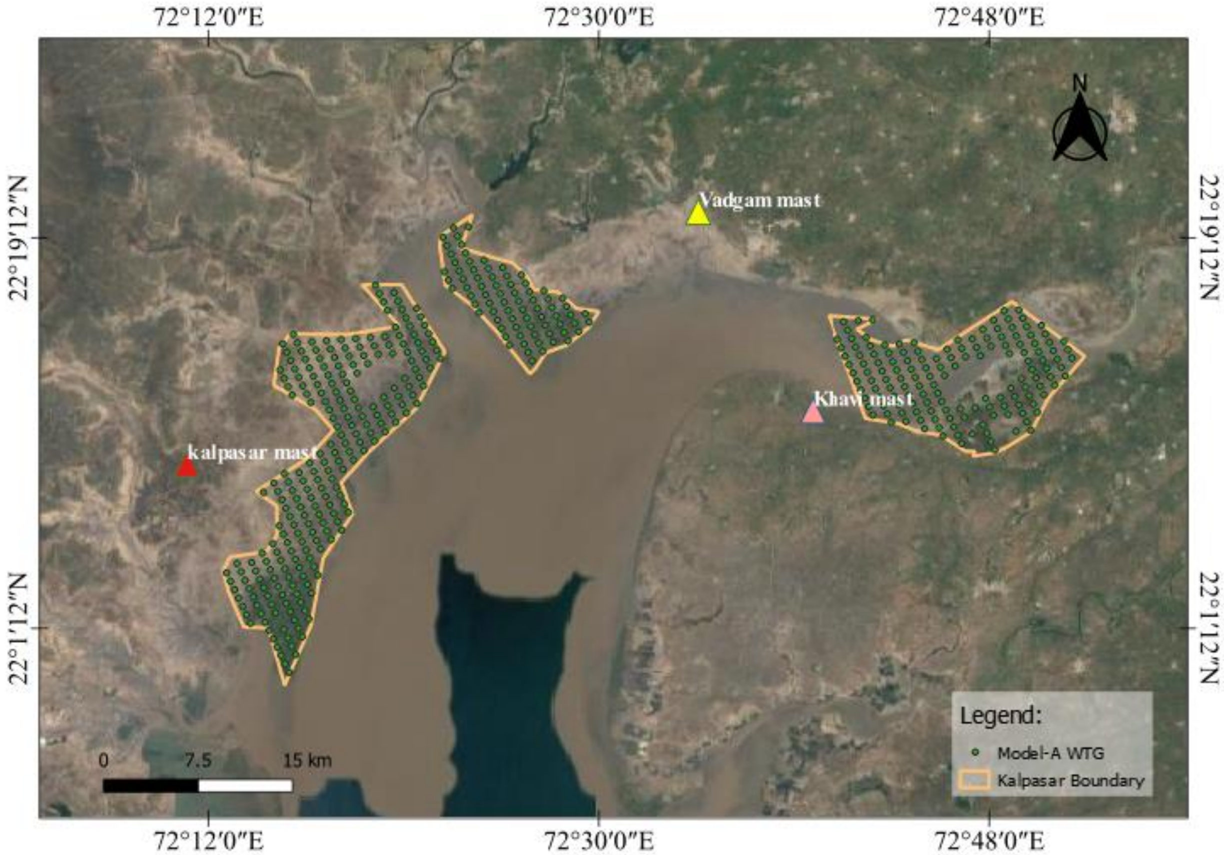


Figure 13.2: Micrositing Layout for Model A

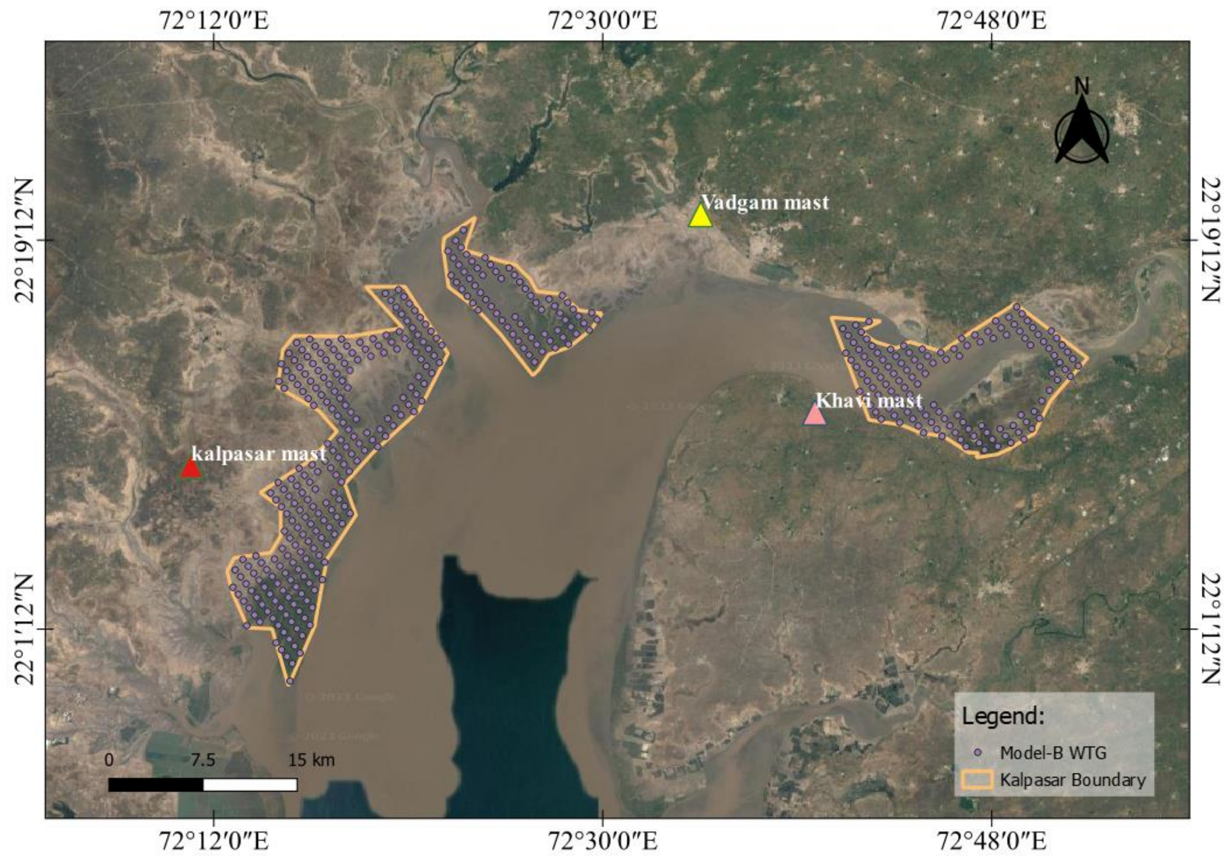


Figure 13.3: Micrositing Layout for Model B

13.2.4 Energy Yield Estimation Summary

Based on the study, it was deduced that the average wind generation profile, when combined with solar generation, can meet the dam's energy needs in most months, with the annual average generation from wind expected to be 3522.88 GWh with a % CUF of upto 26.8 % at the P90 probability exceedance level. The estimated Annual Energy production (AEP) is displayed in Tables 13.5.

Table 13.5. Estimated AEP & %CUF for the wind farm using different wind turbine models

Wind Turbine Models		
	Model A	**Model B**
Rated Capacity of the Turbine (MW)	3.3	3.465
Rotor Diameter (m) & Hub height (m)	156 & 140	145 & 127.5

Total number of Turbines		455	433
Wind Farm Capacity (MW)		1501.5	1500.3
Cumulative Energy Generation (GWh) for 20 Years	P50	4823.04	4463.06
	P75	4229.74	3877.25
	P90	3695.75	3350.00
	P95	3376.18	3034.47
Capacity Utilization Factor (%) for 20 Years	P50	36.67	33.96
	P75	32.16	29.5
	P90	28.10	25.49
	P95	25.67	23.09

13.3 Solar energy

In addition to the wind farm, a 1000 MW capacity solar power plant is being proposed for implementation. In this study, the solar farm layout is designed subsequent to the design of the wind farm layout (detailed in trailing section). In order to avoid the shadow impact, a circular mask has been applied to each wind turbine to the extent of fall off distance (Hub height of wind turbine + ½ rotor diameter of wind turbine + 5m) and the solar panels are proposed in the remaining area. After exclusion of fall-off distance area, we could find ample amount of land for the development of the proposed 1000 MW solar farm (assuming 1 MW of solar farm development will require 4 acres of land). Tentatively, 1000 MW solar PV plant with PV panel fixed tilt at 220 will consist of 80000 numbers of full Tables (strings) and the same can be accommodated at the site.

The monthly solar radiation is as shown in Figure 13.4 and the comparison of monthly solar radiation is as displayed in Figure 13.5, which has been referred from Global Solar Atlas.

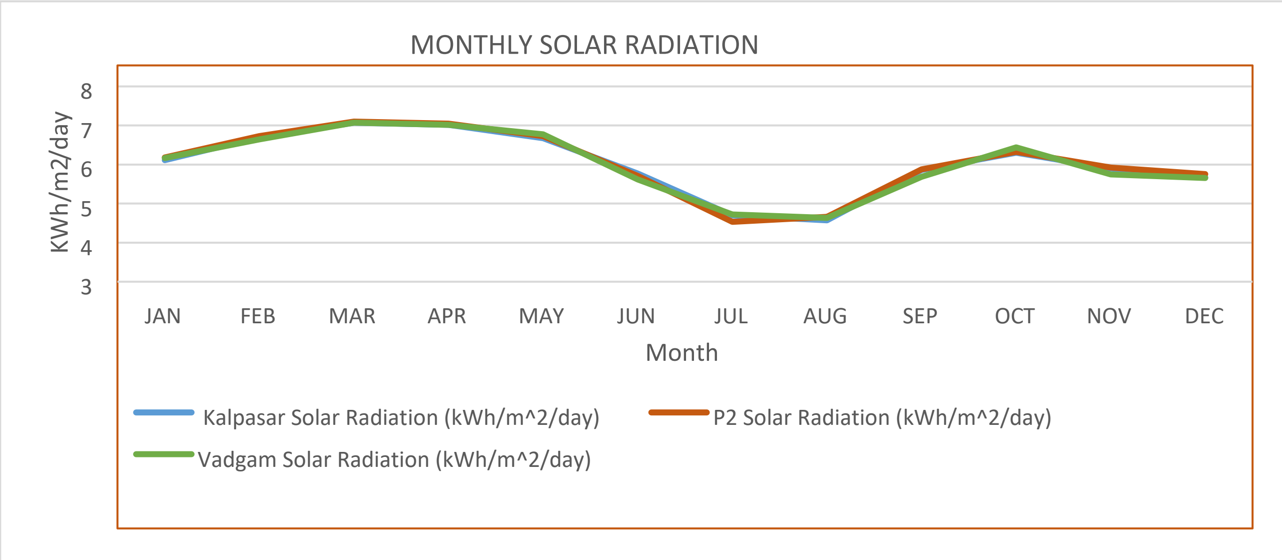


Figure 13.4: Monthly solar radiation (Global Solar Atlas)

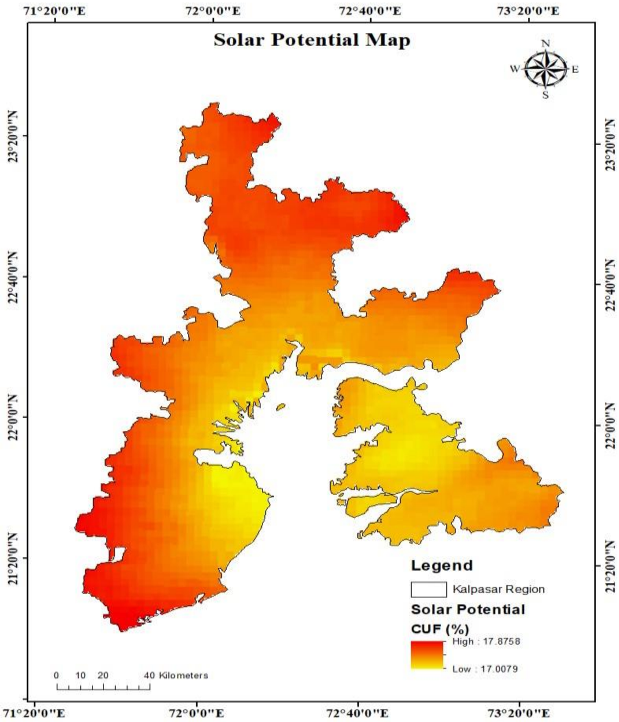


Figure 13.5 Solar Potential of Kalpasar Region (NIWE Solar Atlas)

The PVsyst software was used for calculation of Solar %CUF for the region. NIWE's solar Atlas data was considered for Meteo data. Based on the calculation, the Performance Ratio of the region is 82.49%, which is shown in Figure-13.6 and the CUF is estimated as 17.91%. The CUF estimation has been carried out based on 1:1 – DC: AC ratio assumption. The assumed module used for the calculation are mention below and the performance ratio of the region is shown in the Figure 13.6.

Tilt/Azimuth			22°
PV module	**Unit Nom. Power**		500 Wp
	Number of PV modules		2000000 units
	Modules		80000 Strings x 25 in series
	Total PV power	**Nominal (STC)**	1000000 kWp
		Total	2000000 modules
		Module area	4778496 m²
Inverter	**Unit Nom. Power**		4000 kWac
	Number of inverters		250 units
	Total power		1000000 kWac
	Operating voltage		802-1500 V
	Pnom ratio (DC:AC)		1.00
	Total inverter power	**Total power**	1000000 kWac
		No. of inverters	250 units
		Pnom ratio	1.00
Array losses	**Array Soiling Losses (Loss Fraction)**		3.0 %
	Module mismatch losses		1.0 % at MPP
	Strings Mismatch loss		0.1 %
	DC wiring losses		1.5 % at STC
	Series Diode Loss		0.1 % at STC
Produced Energy			1569 GWh/year
Perf. PR Ratio (Performance Ratio)			82.49 %
%CUF			17.10 %

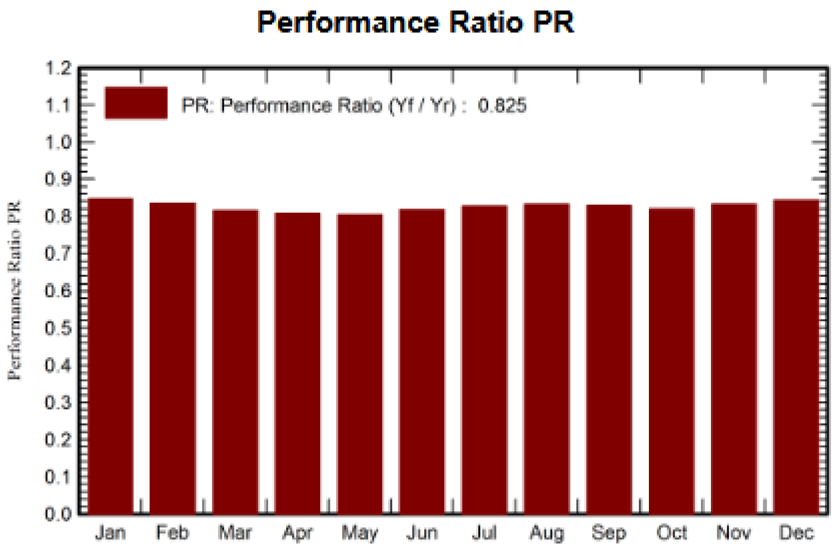


Figure 13.6 - Performance Ratio of the region

13.3.1 Power Evacuation Analysis and Summary

The wind and solar farms will supply power to a dedicated pooling substation with a voltage of 220/33 kV or 400/33 kV, depending on the voltage level at which the Gujarat state transmission utility grants connectivity. According to the power evacuation study, the pooling sub-station will be connected to the grid sub-station at 400 kV or 220 kV. Based on the Literature review, PGCIL has carried out power system studies for grid strengthening and evacuation of approx. 15 GW power from Khavda potential RE zone in the northern part of Gujarat and 5 GW of capacity from the Dholera Ultra Megawatt Solar project by 2025. The proposed 765 kV transmission corridor from Khavda – Halvad- Vataman- Kosamba is one of the possible options for evacuating power from the Kalpasar wind-solar farm.

Since the site is on the coast, the soil conditions has to be tested, such that suitable foundation can be installed and specific clearances such as CRZ clearance must be investigated for the project's effective execution. Because the proposed region is closer to salt farming, a proper foundation must be established, and the project's cost will rise as a result. In addition, we considered the boundary region in terms of future realities.

13.4 Indicative Financial Evaluation

13.4.1 Indicative Financial Evaluation for Wind

Based on the energy estimation analysis, NIWE has carried out an indicative financial evaluation by assuming %CUF as 26.8% for wind farm. The components of the financial estimation are shown in the Table 13.6. As a result, Levelised Tariff for 25 Years (Rs./KWh) is estimated to be 4.07 Rs/kWh. Considering the size of the project and soil conditions, the project cost is assumed to be Rs.700 Lakhs / MW.

Table 13.6 – Indicative Financial Evaluation

<table>
<tr><th colspan="3">Project Inputs</th><th>units</th></tr>
<tr><td>Project Cost</td><td colspan="2">700.00</td><td>Lakhs</td></tr>
<tr><td>Debt Portion</td><td colspan="2">70</td><td>%</td></tr>
<tr><td>Equity Portion</td><td colspan="2">30</td><td>%</td></tr>
<tr><td>Debt Portion In Rs.Lakhs</td><td colspan="2">490.00</td><td>Lakhs</td></tr>
<tr><td>Equity Portion In Rs.Lakhs</td><td colspan="2">210.00</td><td>Lakhs</td></tr>
<tr><td>Repayment of Loan In Years</td><td colspan="2">15</td><td>years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">8.00</td><td>%</td></tr>
<tr><td>Interest On Working Capital</td><td colspan="2">8.00</td><td>%</td></tr>
<tr><td rowspan="3">Return On Equity (In %)</td><td>1yr To 10th yr</td><td>12</td><td>%</td></tr>
<tr><td>11th yr To 25yr</td><td>12</td><td>%</td></tr>
<tr><td>Avg ROE</td><td>12</td><td>%</td></tr>
<tr><td>Depreciation On Project Cost</td><td colspan="2">4.67</td><td>%</td></tr>
<tr><td>O & M Expenses @ 1.5% Of Capex</td><td colspan="2">10.50</td><td>Lakhs/MW</td></tr>
<tr><td>O & M Escalation Per Annum In %</td><td colspan="2">3.84</td><td>%</td></tr>
<tr><td>Life Period</td><td colspan="2">25</td><td>years</td></tr>
<tr><td>Depreciation</td><td colspan="2">3% from 11th year onwards</td><td>%</td></tr>
</table>

In addition to this, the foundation cost has to be analysed in considering the type of foundation used in the region, since the region is near the coastal line.

Considering the possibility of variation in project cost and estimated energy yield, the sensitivity analysis (LCOE) has been carried out by increasing and decreasing in the project cost with respect to CUF values, as shown in the Table 13.7.

Table 13.7 – Sensitivity Analysis for Project Cost and CUF

Project cost/CUF	24%	26%	28%	30%
5% increase in Project cost	4.77	4.40	4.09	3.81
10% increase in Project cost	4.99	4.61	4.28	4.00
5% decrease in Project cost	4.31	3.98	3.70	3.45
10% decrease in Project cost	4.09	3.77	3.50	3.27

13.4.2 Indicative Financial Evaluation for Solar

The indicative financial evaluation for Solar plant is carried out by assuming 18% CUF. The financial components are shown in Table 13.8. As a result, Levelised Tariff for 25 Years (Rs./KWh) is estimated as 3.60 Rs/kWh. Considering the huge size of the project, the project cost is considered as Rs.400 Lakhs / MW.

Table 13.8 – Indicative Financial Evaluation

<table>
<tr><th colspan="3">Project Inputs</th><th>units</th></tr>
<tr><td>Project Cost</td><td colspan="2">400.00</td><td>Lakhs</td></tr>
<tr><td>Debt Portion</td><td colspan="2">70</td><td>%</td></tr>
<tr><td>Equity Portion</td><td colspan="2">30</td><td>%</td></tr>
<tr><td>Debt Portion In Rs.Lakhs</td><td colspan="2">280.00</td><td>Lakhs</td></tr>
<tr><td>Equity Portion In Rs.Lakhs</td><td colspan="2">120.00</td><td>Lakhs</td></tr>
<tr><td>Repayment of Loan In Years</td><td colspan="2">15</td><td>years</td></tr>
<tr><td>Interest Rate</td><td colspan="2">8.00</td><td>%</td></tr>
<tr><td>Interest On Working Capital</td><td colspan="2">8.00</td><td>%</td></tr>
<tr><td rowspan="3">Return On Equity (In %)</td><td>1yr To 10th yr</td><td>12</td><td>%</td></tr>
<tr><td>11th yr To 25yr</td><td>12</td><td>%</td></tr>
<tr><td>Avg ROE</td><td>12</td><td>%</td></tr>
<tr><td>Depreciation On Project Cost</td><td colspan="2">4.67</td><td>%</td></tr>
<tr><td>O & M Expenses @ 2% Of Capex</td><td colspan="2">8.00</td><td>Lakhs/MW</td></tr>
<tr><td>O & M Escalation Per Annum In %</td><td colspan="2">3.84</td><td>%</td></tr>
<tr><td>Life Period</td><td colspan="2">25</td><td>years</td></tr>
</table>

Depreciation	3% from 11th year onwards	%

The results of the sensitivity analysis is shown in the Table 13.9.

Table 13.9 – Sensitivity Analysis for Project Cost and CUF

Project cost/CUF	17%	18%	20%	22%
5% increase in Project cost	4.06	3.84	3.45	3.14
10% increase in Project cost	4.26	4.02	3.62	3.29
5% decrease in Project cost	3.68	3.47	3.13	2.84
10% decrease in Project cost	3.48	3.29	2.96	2.69

13.5 Benefits of the projects

With the development of this project, numerous benefits can be accrued at the Kalpasar dam project, which includes.

1. Wind and solar energy generation can meet the dam's power demand. As a result, the irrigation process and overall rural development can be facilitated.
2. A wind energy project with a capacity of 1500 MW has been proposed for the land. Furthermore, a 1000 MW Solar PV power project is proposed for the land beneath and near wind turbines, resulting in a non-polluting green dam.
3. Altogether, the proposed wind-solar farm can generate approx. 5091.88GWh/year
4. Approx. 4675 Kilo-tonne CO2 emission can be avoided (0.85kg CO2 for 1 kWh) per year
5. Environmental imbalance is avoided as a result of the reduction of climate change and other environmental pollution, which helps India meet its target of 500 GW of renewable energy by 2030.
6. The cost per kWh is competitive with rising costs for conventional power projects. It serves as a hedge against the price volatility of fossil fuels, ensuring energy security and preventing conflict over natural resources.

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