

REPORT ON OFFSHORE WIND PROFILE MEASUREMENT AT DHANUSKODI

(Preliminary Studies & Measurement Campaign)

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EXECUTIVE SUMMARY

In India, the onshore wind energy technologies and developments have reached a matured phase but, the offshore wind potential of the country remains unexplored and hence unexploited, so far. With this into mind, from the Government side, various initiatives are being taken for the offshore wind development in the country through preliminary assessments, collaborative studies, etc., through National Institute of Wind Energy (NIWE), MNRE, Chennai. As a part of the study, NIWE was assigned to commission a specially designed (with corrosion resistive features) 100m tall meteorological mast at Dhanushkodi, Rameshwaram for the wind profile measurement.

Through various preliminary studies, it has been revealed that the coastal line of Gujarat and southern part of Tamil Nadu (especially in Rameshwaram and Kanyakumari regions) seem to have very good wind potential. Some of the studies concluded that there is a possibility to develop 1 GW Offshore wind Power each at Rameshwaram & Kanyakumari. The study also mentioned that the data required validation by measurement in the sea by establishing wind masts.

As an initiative towards validation, NIWE has installed a 100m met-mast at Dhanushkodi and the wind data has been monitored since October 2013. Based on the analysis, the monthly average wind speed at 102m found to be with an annual average of 8.65 m/s. The estimated energy density for the wind speed records is averaged 536 W/m². By considering the operative zone of wind turbines as 4 m/s – 25 m/s, it is safe to quote that **90%** of time a multi-megawatt modern day turbine can be in the operative zone at Dhanushkodi site. Overall, the results obtained from the measurement campaign are promising and encouraging.

This document briefs about the initiatives taken by the Government for the offshore wind energy harnessing and details about the first offshore met-mast measurement campaign being carried out by NIWE at Dhanushkodi, Rameshwaram.

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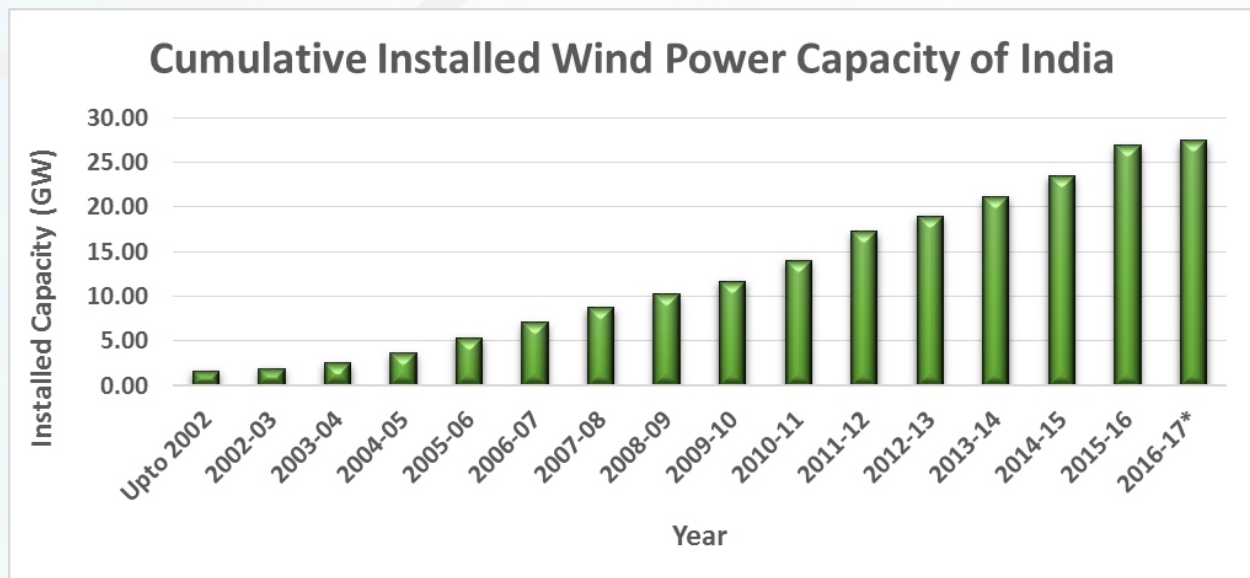
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1.0 Background

India is one of the developing countries and wind energy is one of the non-ignorable sources in Indian energy mix gradually becoming the mainstream energy in the seasons in some states of India. With advancement in technologies and innovation in design and manufacturing, the sector is growing steadier in the country. As on 31.07.2016, wind power has contributed more than 27 GW (27441.15 MW) [1] of India's installed capacity. The year-wise growth of on-shore wind power in India is pictorially represented in Figure 1. Government of India has made an ambitious goal to install 60,000MW of wind power by 2022 is highlighting the needed focus on the green power's contribution in India's sustainable development. In India, the onshore wind energy technologies and developments have reached a matured phase and at some sites even become competitive with fossil fuel based electricity generation.



*upto 31.07.2016

Figure 1: Installed Wind Power in India
(Source: IWPA & MNRE)

However, the offshore wind potential of the country remains unexplored and hence unexploited, so far. One of the significant advantages for going offshore is that it is free from any obstruction and surface roughness is very smooth. This gives a consistent and smooth flow of winds over the sea with lesser turbulence level. Offshore wind energy has a reduced effect on the environment and higher wind speeds at sea, result in increased energy production. Leading wind energy producers in UK, Europe, China and Germany are embracing offshore wind as an important component of future expansion and exploration of renewable energy from wind.

In India, where prior experiences for offshore development of wind farm have not yet been set, where a lot of essential data sets (viz., measured wind data, correlated Mesoscale models, detailed EIA studies, Oceanographic studies, etc.,) are not available readily, where at the initial phase, the social response and clearance activities seem to be a black box, it is justifiable that any developer would expect a detailed road map from the government with authenticated studies and technologies to follow up to harness the offshore wind potential. The same will also be helpful for the government to amend the policies before entering into a mass development phase in the offshore.

For any new offshore market, the cost drivers associated with different technologies vary significantly. The environmental constraints, sea bed conditions and structure, the wind resource, array layout & grid connection, as well as the turbine technology for the site and the installation methods, all have to be mapped out in detail to understand the scale of the opportunity and capital expenditure required to realize the development. The cost of an offshore project is massive and will escalate quickly as a function of sea bed conditions and water depth apart from operating wind climate conditions. Based on the UK experience, by considering the scale and volume, a single offshore wind project can be considered as a country wide, national level onshore development, a huge challenge [2]. With this into mind, from the government side, various initiatives are being taken for the offshore wind development in the country through preliminary assessments, collaborative studies, etc., through National Institute of Wind Energy (NIWE), MNRE, Chennai. As a part of the study, NIWE was assigned to commission a 100m tall meteorological mast at Dhanushkodi, Rameshwaram for the wind profile measurement.

The "National Offshore Wind Energy Policy" has also been recently released after the approval of the Cabinet, to enable optimum exploitation of (1st October 2015) Offshore Wind Energy in the best interest of the country. As per the policy, Ministry of New & Renewable Energy (MNRE) will act as the Nodal Ministry for development of offshore wind power in the EEZ (Exclusive Economic Zone) of the country and National Institute of Wind Energy (NIWE) will act as the Nodal Agency for exploration and exploitation of offshore wind power in the EEZ of the country and carry activities such as call for proposal, entering into contract with developer and collection of lease fee. Further details can be found in the reference [3].

This document briefs about the initiatives taken by the government for the offshore wind energy harvest and details about the first offshore met-mast measurement campaign being carried out by NIWE at Dhanushkodi, Rameshwaram.

1.1 Scope of the study

- a) To review the preliminary offshore wind potential studies carried out with various available data sources in the Indian coastal line.
- b) To investigate the data measured from the specially designed (anti-corrosion specifications) & installed 100m guyed meteorological mast at Dhanushkodi, Rameshwaram towards facilitating offshore wind farm development in India.

2.0. Preliminary Studies

India is blessed with a long coastline of 7516 kms (inclusive of Islands) and an Exclusive Economic Zone (EEZ) of nearly 2 million sq.kms (NIO, Dona Paula, Goa). The United Nation convention on law of the sea gives India the exclusive rights over its Economic Exclusive Zone (200 Nautical Miles from baseline) within which it can exercise sovereign rights in relation to activities such as Fisheries, production of energy from water currents and wind. In addition it has exclusive rights to construct, authorize and regulate the construction, operation and use of installation for this purpose.

In order to assess the wind pattern and potential along the coast NIWE (National Institute of Wind Energy) (formerly Centre for Wind Energy Technology (CWET)) had measured wind data from 74 metrological masts at different coastal locations, which are shown in Figure 2. The preliminary desk-top studies revealed that the coastal line of Gujarat and southern part of Tamil Nadu seem to have very good wind potential especially in Rameshwaram and Kanyakumari regions. NIWE had also carried out 14 days wind profile study during 2009 by using sound based remote sensing instrument called SODAR (Sound Detection and Ranging) instrument at Dhanushkodi, Rameshwaram. The study revealed that at 120 meter height, the 10 min average wind speed was 19.3 m/s for the measured short period. Apart from these studies, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad had conducted wind profile measurements and concluded that the possible wind speed of 6-8 m/s in the offshore at 80 m height and are prevailing mostly along the coast. Tamil Nadu region has winds more than 8 m/s for 200 days, while Gujarat coast has winds more than 8 m/s for about 100 days. Southern Coast of Tamil Nadu and the Coast of Gujarat-Maharashtra are the identified areas of indicative higher wind potential as per the INCOIS study.

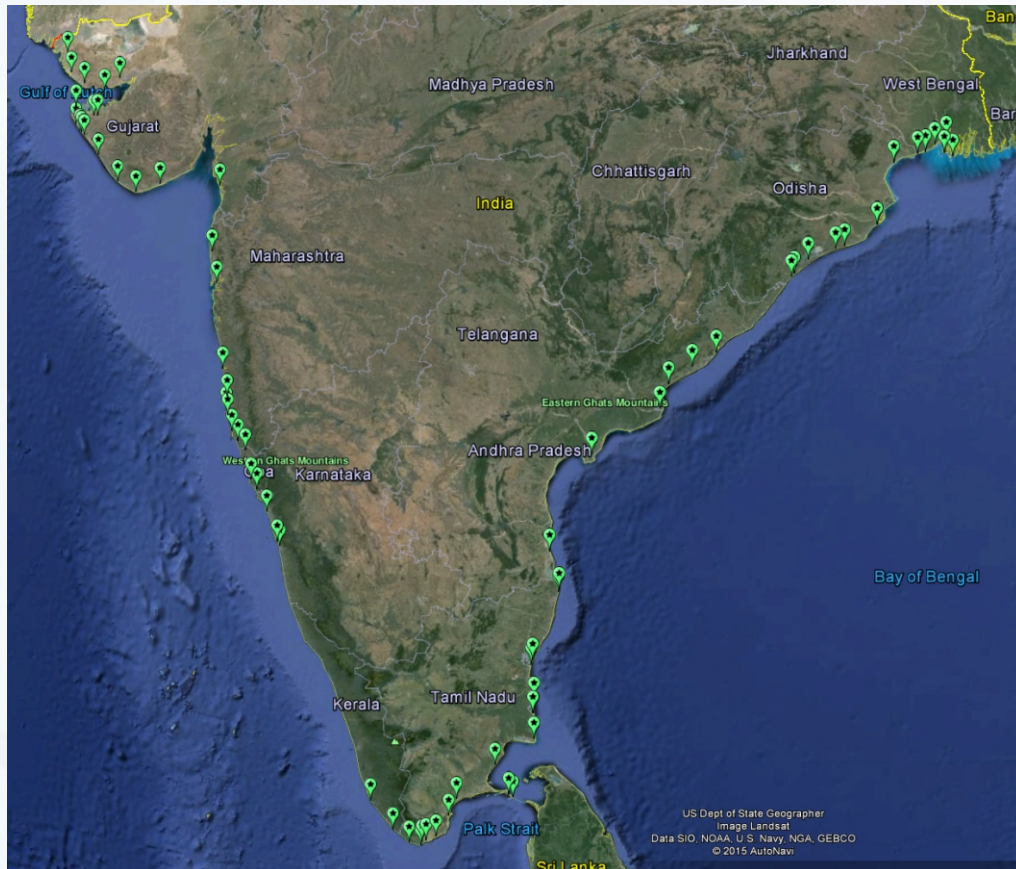


Figure 2: Coastal Mast Locations

During the preparation of the Indian Wind Atlas, RISO DTU Denmark along with NIWE indicated some offshore wind potential around the coastline of South India at 80m agl [4] as shown in Figure 3. In continuation to this, NIWE had carried out satellite-based wind resource mapping in a small region between Rameshwaram and Kanyakumari in the southern part of Tamil Nadu in collaboration with Risø/DTU, Denmark facilitated through a MNRE/CFA funded project. The measurement and analysis was based on the satellite synthetic aperture radar (SAR) data from the European Space Agency (ESA) conducted ENVISAT/ASAR mission. The major advantage of using satellite SAR data for offshore wind mapping lies in the high spatial resolution of the data and the coverage of coastal waters. A total of 164 SAR images covering 10 years (2002 – 2011) were utilized for the project. The 10m-high wind speeds were retrieved from SAR images and a statistical analysis was performed with the S-WASP tool developed at Risø/DTU. The study revealed that the candidate region had very high wind power potential for offshore wind farm development. The wind speed map prepared using the SAR images is shown in Figure 4. As per the study, the mean wind speed near the coast may be around 4 to 5 m/s whereas up to 7.6 m/s may be found further offshore indicating wind resources from 200 to 500 W/m² [5].

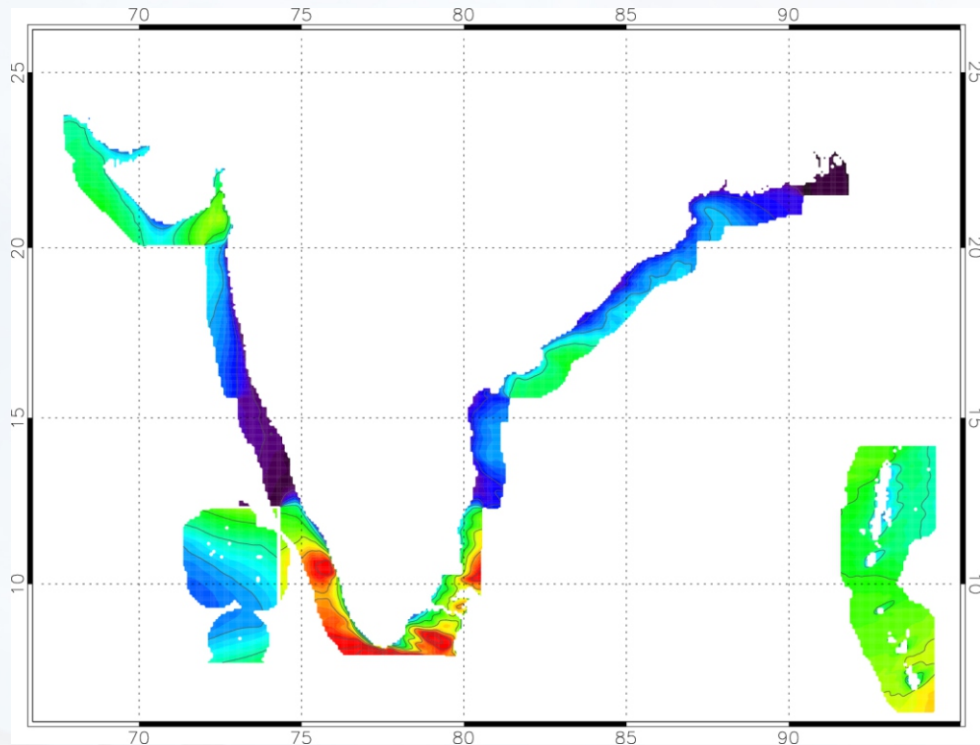


Figure 3: Offshore mean simulated wind power density at 80 m agl.
The contour interval is 100 W/m^2

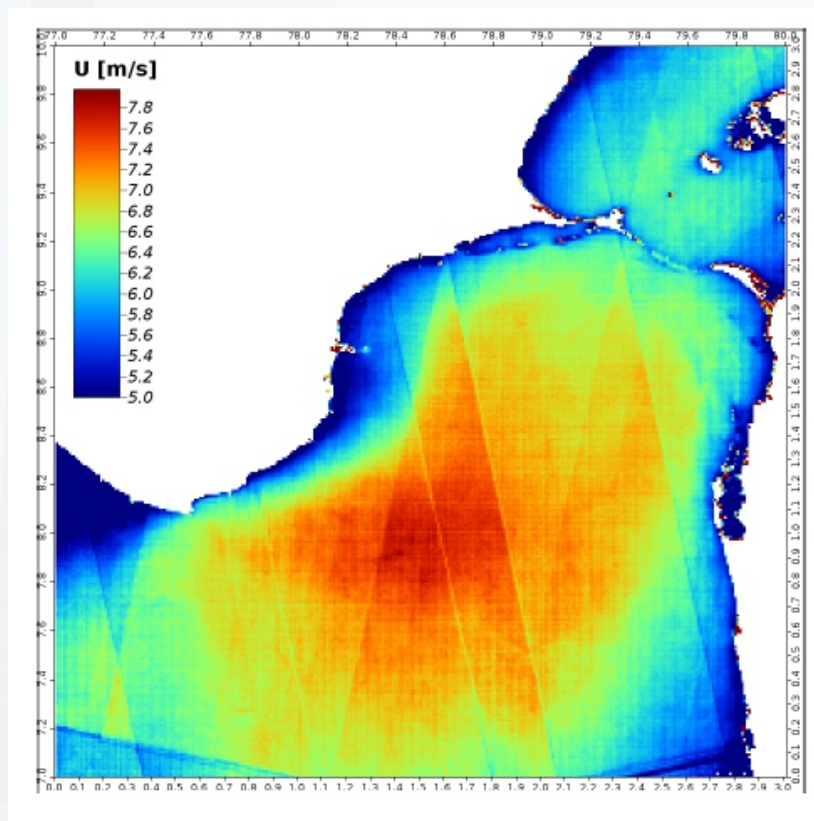


Figure 4: Mean Wind Speed from 164 ENVISAT ASAR wind maps offshore in South India

In continuation to the SAR study, a preliminary energy study has been conducted by the Scottish Development International (SDI, UK) and NIWE for the Tamil Nadu Offshore region. The study concluded that there is a possibility to develop 1 GW Offshore wind Power each at Rameshwaram & Kanyakumari. The study also mentioned that the data required validation by measurement in the sea by establishing wind masts. From the various studies on potential for establishing offshore wind farm, it is estimated that there may be potential for around 5 GW of wind power along the shallow water offshore region of India. The studies may need to be extended up to 50 miles in the sea from baseline to get the total possible wind resource potential, however keeping a watch on the water depth to be within limits (less than 30m as of now) for economic viability of the projects.

In addition to these studies, a project called Facilitating Offshore Wind in India (FOWIND) is being carried out towards offshore developments in Tamil Nadu and Gujarat. FOWIND project is designed in response to a proposal call under the Indo-European co-operation on Renewable Energy Program and is funded through a grant from European Union. The consortium led by Global Wind Energy Council (GWEC) is implementing the Facilitating Offshore Wind in India (FOWIND) project. The other consortium partners include the Centre for Study of Science, Technology and Policy (CSTEP), DNV GL, the Gujarat Power Corporation Limited (GPCL) and the World Institute of Sustainable Energy (WISE). National Institute of Wind Energy (NIWE) joined the consortium as knowledge partner on 15 June 2015. The project focuses on the States of Gujarat and Tamil Nadu for identification of potential zones for development through techno-commercial analysis and preliminary resource assessment. Recently, as a part of the project, pre-feasibility reports for the offshore wind farm development in Tamil Nadu and Gujarat have been released. The project activities will be implemented from December 2013 to March 2018 [6].

Though the satellite data gives estimation of wind speeds over the ocean surface and provide an excellent overview of the ambient wind conditions in the ocean areas off the coast of India, due to inherent uncertainties with the satellite-based estimates, they should be compared with measurement data wherever possible. As an initiative towards validation, NIWE has installed a 100m met-mast at Dhanushkodi with offshore wind profile measuring instruments mounted on the mast as a follow-up of (SDI, UK) report. The results reveal that the location has promising offshore wind potential. A detailed data analysis report for the same is discussed in the following pages.

3.0 Dhanushkodi Measurement Campaign

In continuation to the preliminary studies carried out in the Indian waters, NIWE commissioned a 100m high guyed lattice mast in the coastal line of Dhanushkodi, Rameshwaram. The wind data has been monitored since October 2013 and the measurement has been successfully completed for two continuous years (covering both the seasons). In line with this, towards enhancing the knowledge on off-shore wind climatology, NIWE would like to share the detailed data analysis report for the Dhanushkodi measurement for one concurrent year (Oct 2013 to Sept 2014) for the public to attract new stakeholders in Indian Offshore. This data analysis document is expected to motivate the wind turbine manufacturers, investors, developers, bankers, engineers, financial institutions, academicians, massive diesel (oil) consumers, railways, microwave towers, transport fuel and other stake holders towards India's off-shore wind farm development.

3.1. Site Description

The site selected for the measurement is located in the southern tip of Dhanushkodi. The location can be described as one of the ideal site for initial offshore measurement. The site is situated in the shore-line and covered by shallow sea waters in three directions. The soil around the site is loose beach sand. The topography is uniform and very minimum roughness disturbance prevails around the site as the wind fetch through but the year is largely from the ocean or bay water front. The mast location is situated approx. 6.60km from Mukundarayar Chathiram in south east direction and transportation facility is available up to the site even though maneuvering through wet sand is unavailable. The geographical co-ordinates and elevation of the site is as follows.

Latitude : 09° 10' 4.78" N
Longitude : 79° 25' 44.29" E
Elevation : 1m amsl* (based on Google Earth)

The site images are shown in Figure 5 & 6. The site details are tabulated in Table 1.

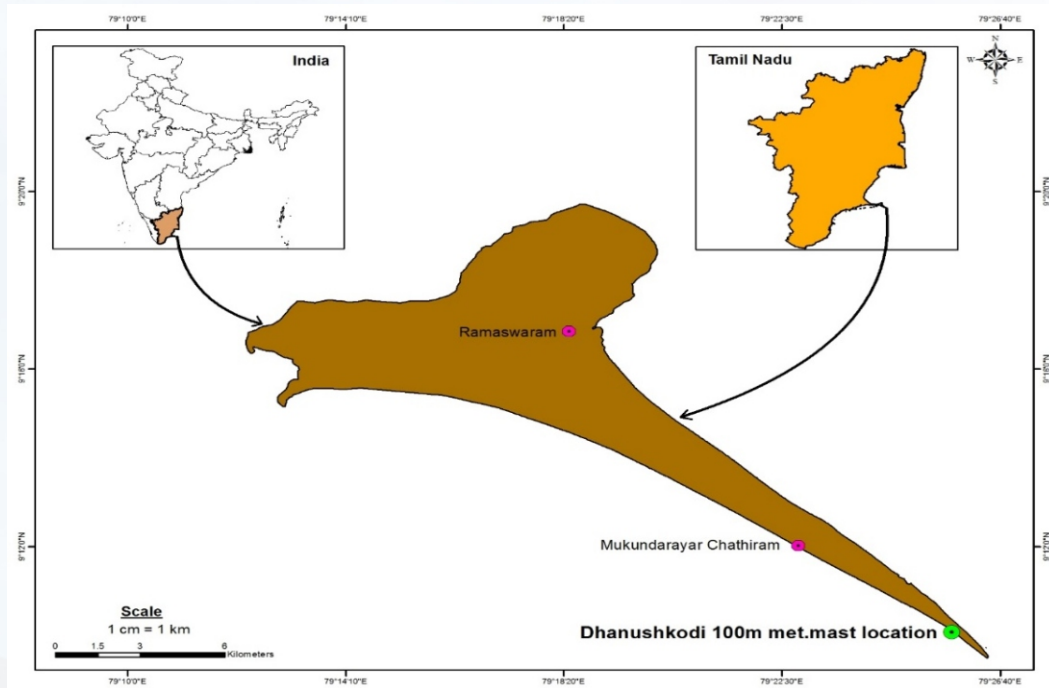


Figure 5: Dhanushkodi Mast Location



Figure 6: Satellite Image of Dhanushkodi Mast Location
(Courtesy: Google Earth)

Table 1: Site Description

Site Name	Dhanushkodi
District Name	Ramanathapuram
State Name	Tamil Nadu
Site Co-ordinate	09° 10' 4.78" N, 79° 25' 44.29" E
Elevation	1m amsl (based on Google Earth)
Orography & Roughness	Homogeneous coastal land strip surrounded by sea waters.
Nearest Village	Mukundarayar Chathiram
Nearest Town	Rameshwaram
Nearest Railway Station	Rameshwaram
Nearest Airports	Madurai & Tuticorin
Approach	Rameshwaram to Mukundarayar Chathiram (via AH43) to Site location (via Ghat Road)
Nearest Electrical Substations	Rameshwaram SS & Mandapam SS

3.2. Instrumentation

A 100m tall lattice meteorological tower was specially designed with corrosion resistance technical specification installed at Dhanushkodi, Rameshwaram, Tamil Nadu site to collect continuous records of wind parameters since October 2013 .The 100m met-mast structure for this project was designed, fabricated, erected and being maintained by M/s. KEC International Limited, Mumbai, who has been selected for the work through open tender. Instrumentation and rectification is being carried out by NIWE engineers. The image of mast is shown in Figure 7. The mast is equipped with 6 calibrated cup anemometers, 4 wind vanes, one Campbell CR100 data logger, three sensors, one each for Temperature, Barometric pressure and humidity measurements respectively and one sonic anemometer at 98 m. It records six level wind velocities (at 10m, 20m, 50m, 80m, 100m and 102m), four wind directions (at 10m, 50m, 80m and 98m) as well as pressure, relative humidity, and temperature of the ambient atmosphere. Wind records are sampled at 1 Hz and averaged over 10 minutes. The values are obtained continuously through the year at every 10 minutes interval from October 2013 through till date. The data is being continuously monitored through online. Corrosion-resistive coating is being painted

frequently over the mast segments to counter the corrosion effects of sea breeze with high humidity & salinity, is a hot tropical climate. All the sensors and instruments used in the study are "first class" sensors and properly calibrated in accredited laboratories. Even though measurement is being carried out with different sensors at different heights, due to non-availability of continuous data, some of the sensors have not been used in this study. The details of the instruments used in this data analysis study are given in Table 2.



Figure 7: Image of Dhanushkodi 100m Mast

Table 2: Details of Instrumentation utilized in the Data Collection

Instrument	Height (m)	Sl. No	Slope	Offset	Make/ Model	Boom Orientation
Data Logger	5	7932	-	-	Campbell/CR 3000	-
Anemometer	102	13510	0.00072	0.03338	Wind Sensor P2546A Cup Anemometer	Top Anemometer
Anemometer	100	13509	0.00116	0.05710		South East
Anemometer	80	13508	0.00074	0.03650		South East
Anemometer	50	13507	0.00124	0.06103		South East
Anemometer	20	13506	0.00098	0.04665		South East
Anemometer	10	13505	0.00118	0.05627		South East
Wind Vane	80	59174	-	-	F2919A Vector Instruments W200P Wind vane	North west
Wind Vane	20	59177	-	-		North west
Temp Sensor	10	263	-	-	P2642A/Campbell	South East
Humidity Sensor	98	J1040006	-	-	Vaisala	South East
Barometer	5	H4740006	-	-	P4002A Vaisala PTB110 Barometer	-

3.3 Data Analysis

In the data logger, wind and related weather data were sampled at 1 Hz frequency and 10 minutes average values were logged. Analysis was performed with 10 minutes average data as per standard practice of wind energy sector. Data were validated manually and also using software to remove outlier events due to occasional failure of instruments or repeated constant values. From the available data, mean values of Wind Speed (WS) and Wind power density (WPD) have been calculated for each month. The wind data analysis summary can be obtained from Table 3. The information about wind speed and WPD are further segregated into month-wise values in Table 4. From Table-4, the highest and lowest monthly mean wind speed values have been found in July 2014 and April 2014 respectively. The air density values calculated at the station are based on the measured temperature (at 10m) and pressure (at 5m, inside logger box), with due correction applicable.

3.3.1 Time Series Profile

A time series profile will be much helpful to understand the variation of parameters within the measured duration in detail and handy in the identification & removal of the erroneous data. The time series profile for the wind speed measurement at 100m for one year is shown in Figure 8.

Similarly, the monthly and diurnal mean wind speed profiles are also shown in Figure 9 & Figure 10 for the visualization. Air density profile calculated using 10m temperature and 5m pressure is shown in Figure 11. The monthly average wind speed at 102m varies between 5.51 m/s and 10.24 m/s with an annual average wind speed of 8.65 m/s. The estimated energy density for these wind speed records is averaged 536 W/m² and it varies considerably during the year.

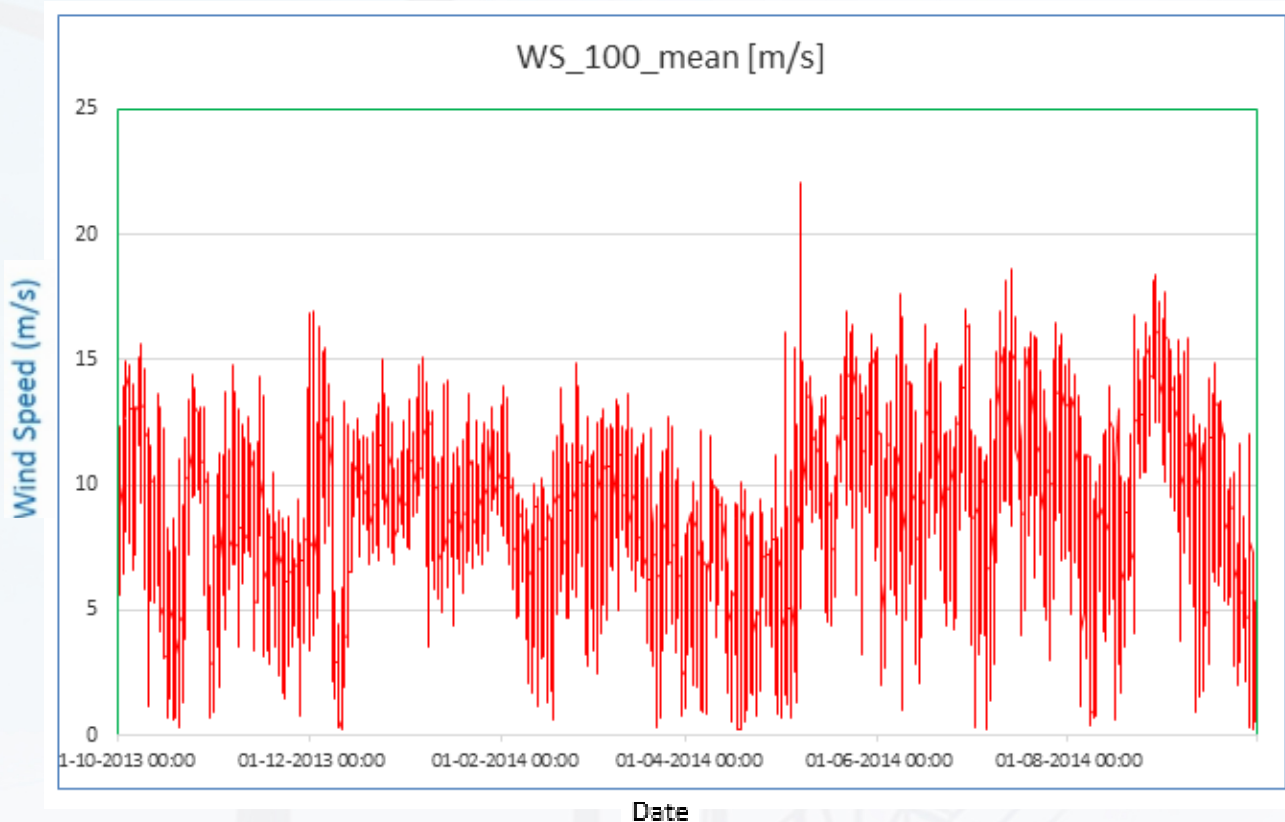


Figure 8: Time Series Profile of Wind Speed at 100m

Table 3: Details of Dhanushkodi wind monitoring station

Station	Dhanushkodi
District	Ramanathapuram
State	Tamil Nadu
Latitude	09° 10' 4.78" N
Longitude	79° 25' 44.29" E
Elevation	1 m (As per Google Earth)
Period of Data taken for Analysis	October 2013 - September 2014
Duration	12 months
Length of the time step	10 minutes
Site Air Density (based on measured temperature at 10m & pressure)	1.168 Kg/m ³
Annual Mean Wind Speed (m/s) @ 102m agl	8.65 m/s
Annual Mean Wind Speed (m/s) @ 100m agl	8.66 m/s
Annual Mean Wind Speed (m/s) @ 80m agl	8.55 m/s
Annual Mean Wind Speed (m/s) @ 50m agl	8.48 m/s
Annual Mean Wind Speed (m/s) @ 20m agl	8.17 m/s
Annual Mean Wind Speed (m/s) @ 10m agl	7.78 m/s
Annual Wind Power Density (W/m ²) @ 102m agl	536 W/m ²
Annual Wind Power Density (W/m ²) @ 100m agl	537 W/m ²
Annual Wind Power Density (W/m ²) @ 80m agl	519 W/m ²
Annual Wind Power Density (W/m ²) @ 50m agl	499 W/m ²
Annual Wind Power Density (W/m ²) @ 20m agl	439 W/m ²
Annual Wind Power Density (W/m ²) @ 10m agl	374 W/m ²

Table 4: Wind Speed & Wind Power Density Table (Oct 2013 - Sep 2014)

Month	102m		100m		80m		50m		20m		10m	
	WS (m/s)	WPD (W/m ²)	WS (m/s)	WPD (W/m ²)	WS (m/s)	WPD (W/m ²)	WS (m/s)	WPD (W/m ²)	WS (m/s)	WPD (W/m ²)	WS (m/s)	WPD (W/m ²)
Oct-13	8.45	538	8.34	515	8.28	506	8.21	487	7.92	430	7.57	372
Nov-13	7.35	303	7.46	319	7.39	310	7.33	301	7.12	274	6.80	235
Dec-13	8.91	542	9.05	569	8.94	549	8.83	529	8.49	466	8.03	392
Jan-14	9.58	562	9.75	592	9.62	568	9.49	544	9.13	484	8.64	408
Feb-14	7.37	318	7.48	334	7.40	323	7.33	312	7.11	282	6.77	240
Mar-14	7.62	343	7.71	357	7.63	345	7.57	335	7.33	301	6.95	254
Apr-14	5.51	144	5.43	137	5.34	131	5.36	131	5.24	122	5.05	108
May-14	10.04	772	9.90	742	9.80	723	9.70	693	9.29	602	8.81	510
Jun-14	9.96	713	9.92	704	9.80	683	9.69	652	9.30	569	8.86	487
Jul-14	10.24	789	10.24	790	10.09	757	9.95	715	9.53	618	9.08	528
Aug-14	9.82	779	9.74	766	9.60	742	9.56	715	9.21	623	8.78	530
Sep-14	8.61	580	8.52	566	8.40	546	8.36	526	8.06	461	7.71	396
Avg	8.65	536	8.66	537	8.55	519	8.48	499	8.17	439	7.78	374

WS - Wind Speed (m/s)

WPD - Wind Power Density (W/m²)

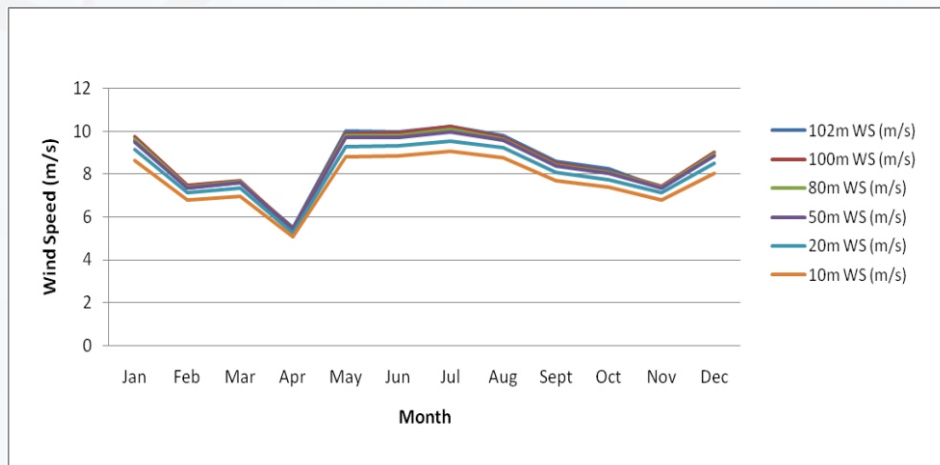


Figure 9: Monthly Wind Profile

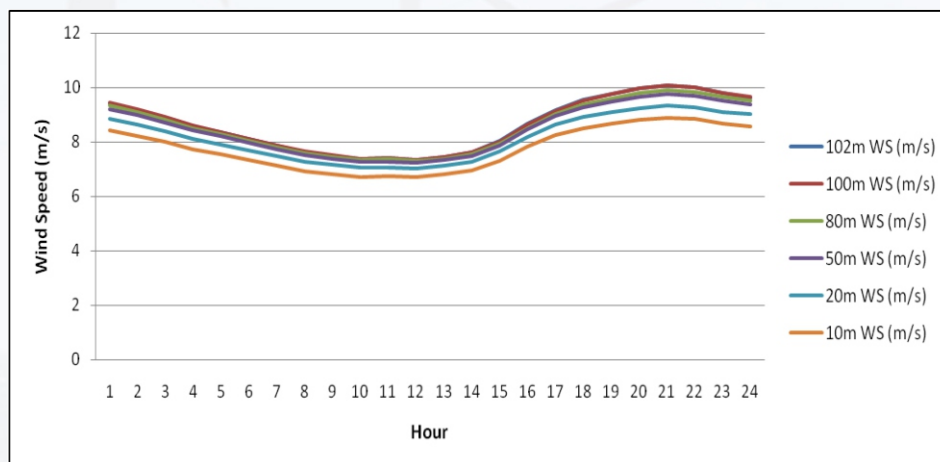


Figure 10: Diurnal Wind Profile

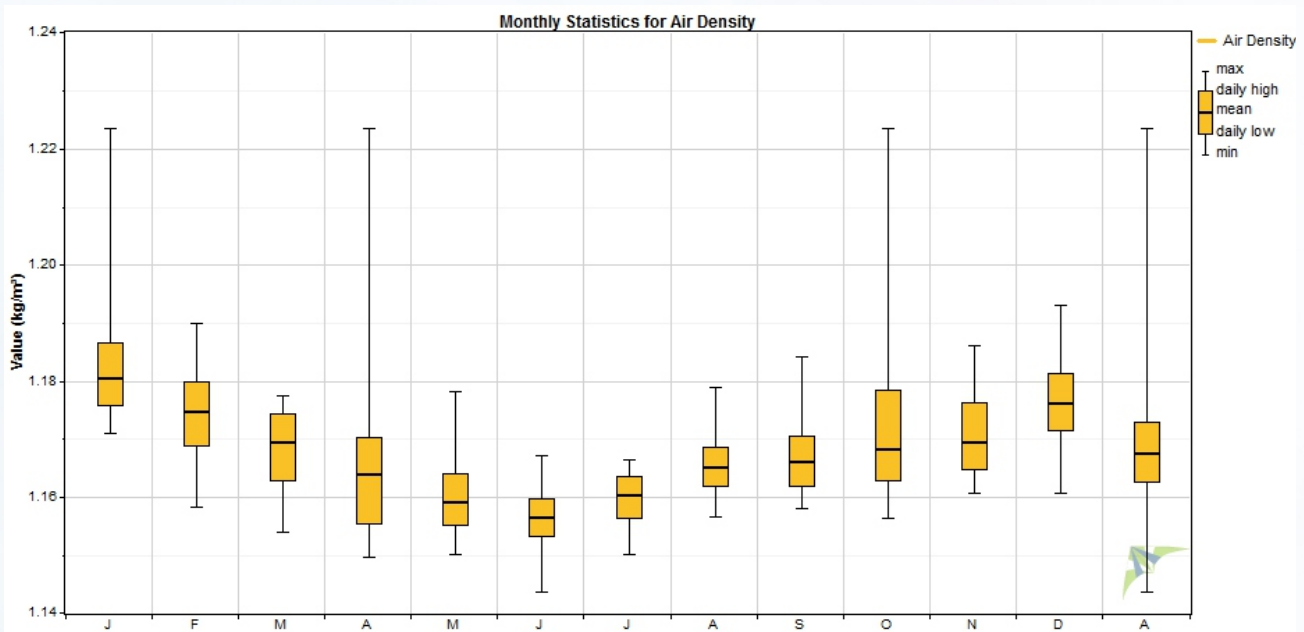


Figure 11: Monthly Air Density Profile (2013 - 2014)
(Based on measured temperature at 10m & pressure at 5m)

3.3.2 Wind Rose - Prevailing wind direction at Dhanushkodi

Three wind vanes (20m, 80m and 98m) have been installed at the mast to measure the 10 minutes mean values of the wind direction. Due to non-availability of concurrent measurement from the 98m wind vane, the wind direction data from the same is not utilized in this year's analysis. The 12 sector wind roses based on 20m and 80m wind vanes are shown in Figure 12. Based on the wind roses, it is revealed that the first predominant wind direction at Dhanushkodi site is SW (South West) and 2nd predominant direction is NE (North East). For details, wind rose at 102m (based on 102m Wind Speed & 80m Wind direction) is segregated by wind speed classes as represented in Figure 13. Figure 14 shows the monthly wind roses at 102m (102m wind speed Vs 80m wind direction) for getting the needed clarity of wind pattern.

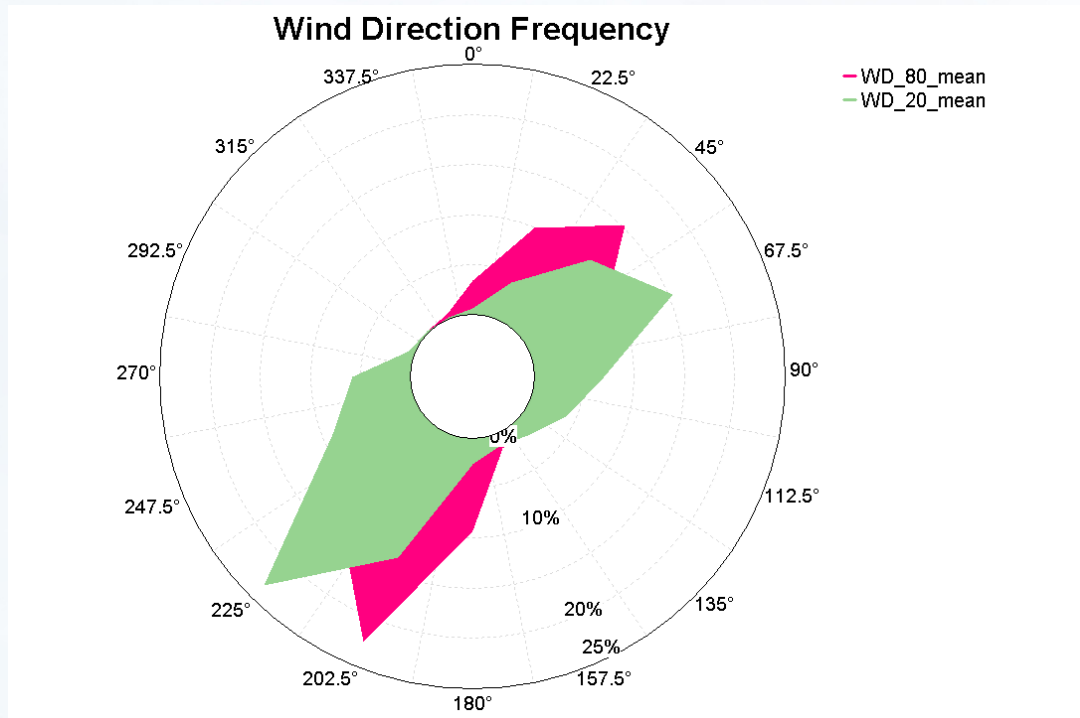


Figure 12: Wind Rose

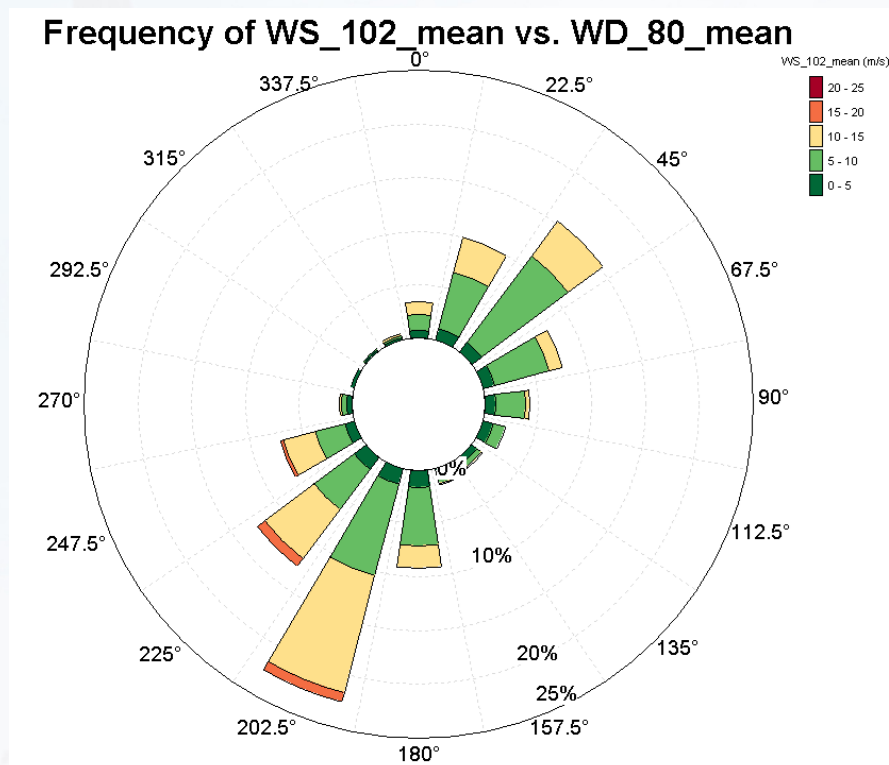


Figure 13: Wind Rose at 102m with wind speed classes (based on 102m wind speed and 80m wind direction)

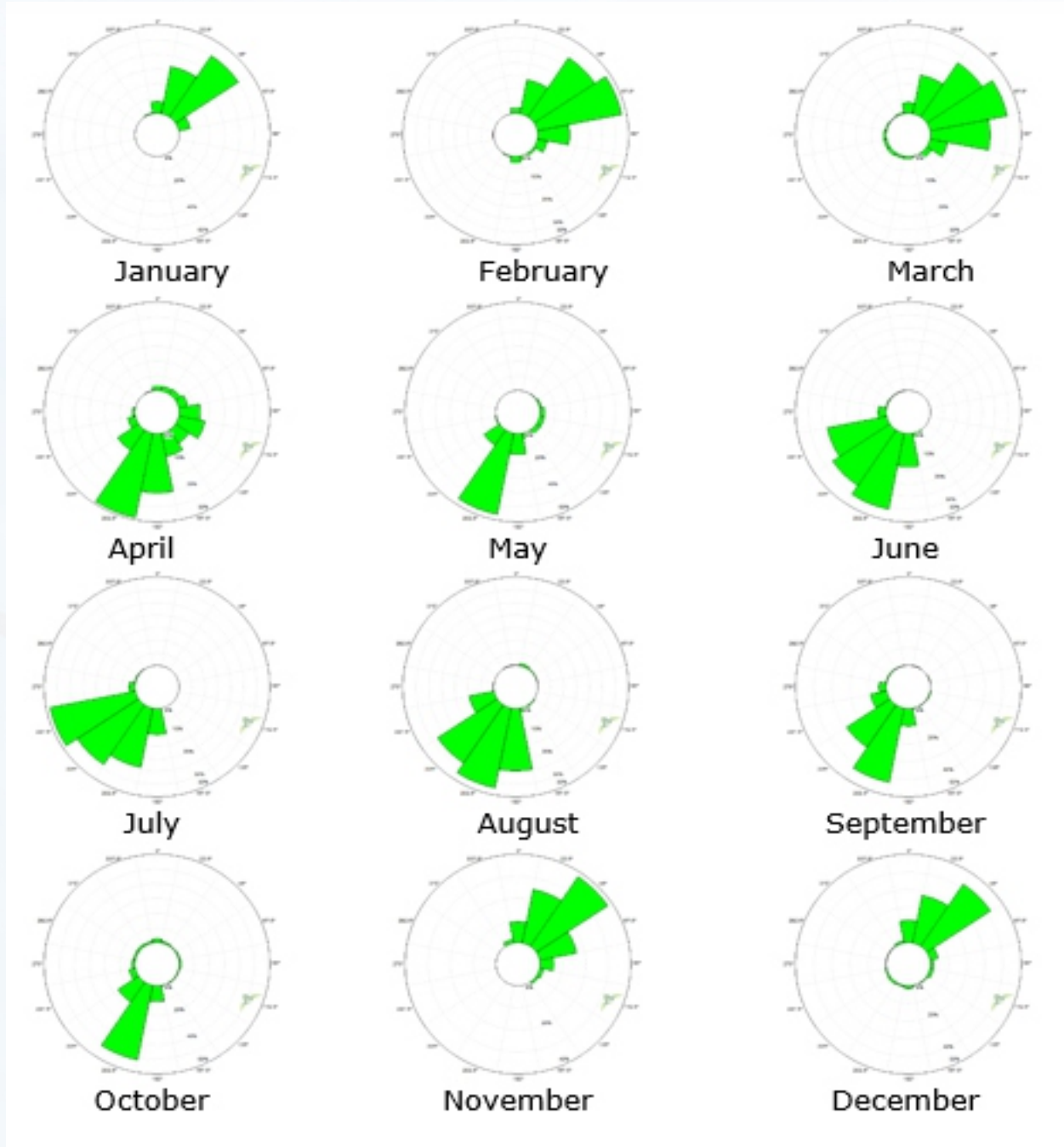


Figure 14: Monthly Wind Roses
(102m Wind speed & 80m wind direction during Oct 2013 - Sep 2015)

3.3.3 Temperature at Dhanushkodi

The temperature at the specific site needs to be examined in the purpose of checking climate conditions. Since this wind measurement project is located in the strip of sand between seas a temperature site classification is considered reasonable. Figures 15 & 16 show temperature time series for Dhanushkodi at site at 98m (as a derivative from the humidity sensor) and 10m from the year Oct 2013 to Sept 2014. The average temperature at 10m for this time series was measured as 27.7 °C. The temperature gradient is also shown in Figure 17.

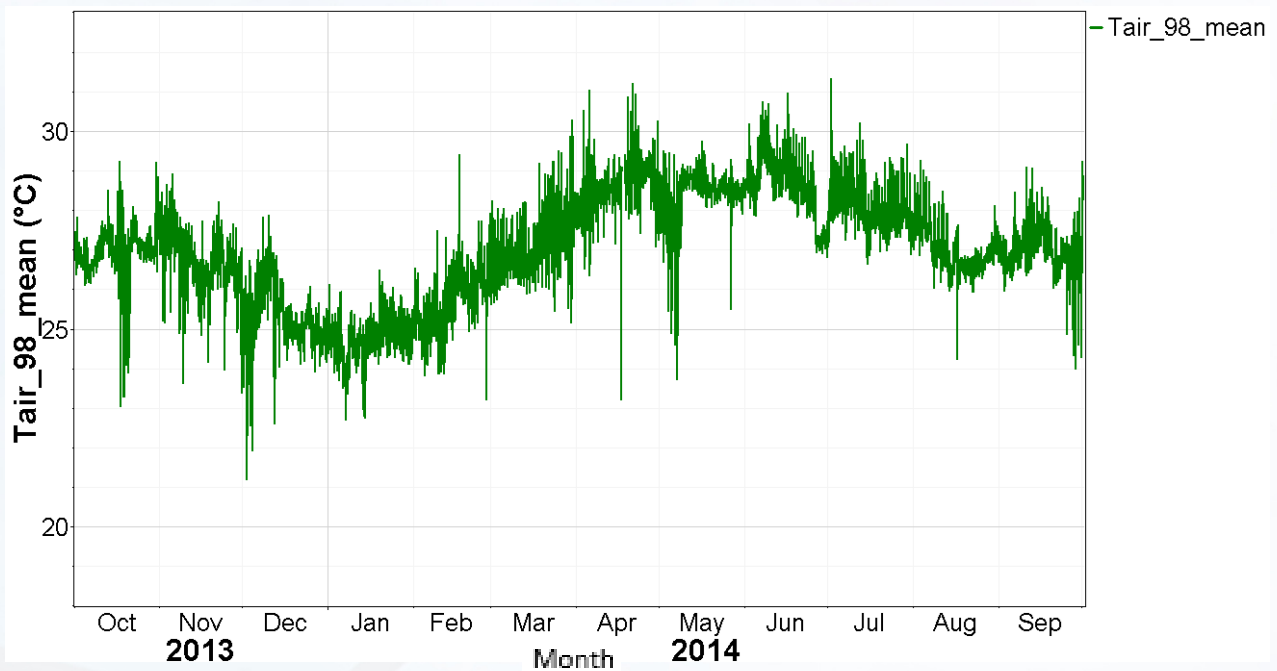


Figure 15: Temperature profile at 98m height

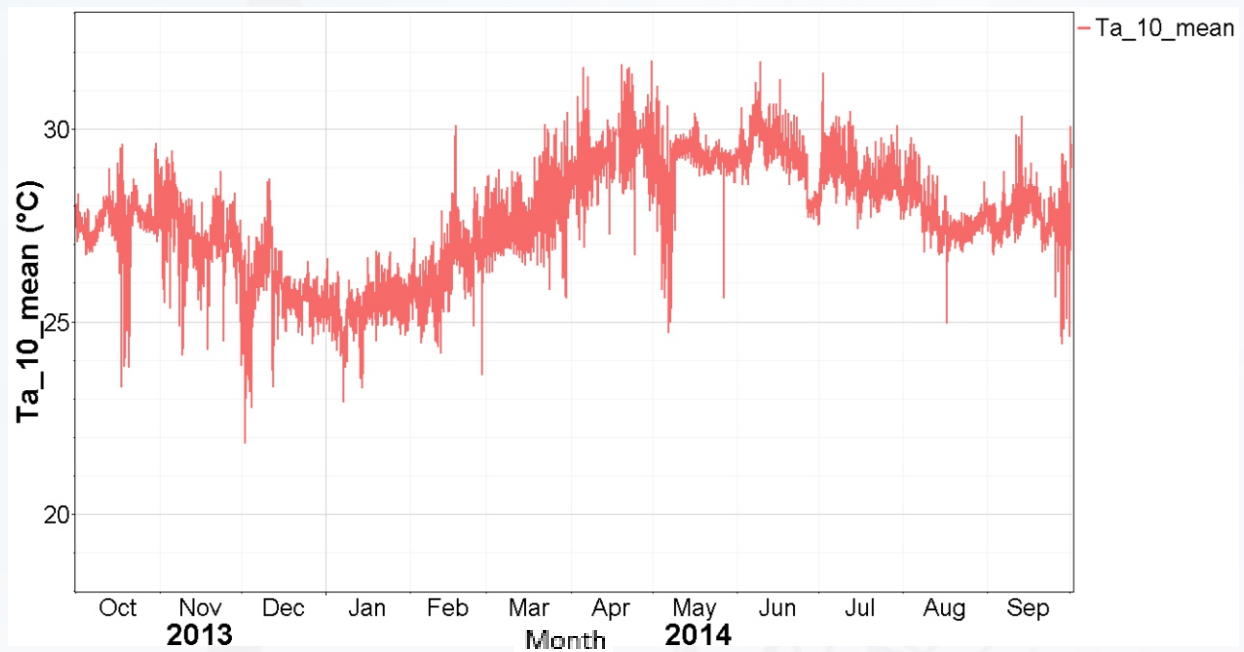


Figure 16: Temperature profile at 10m height

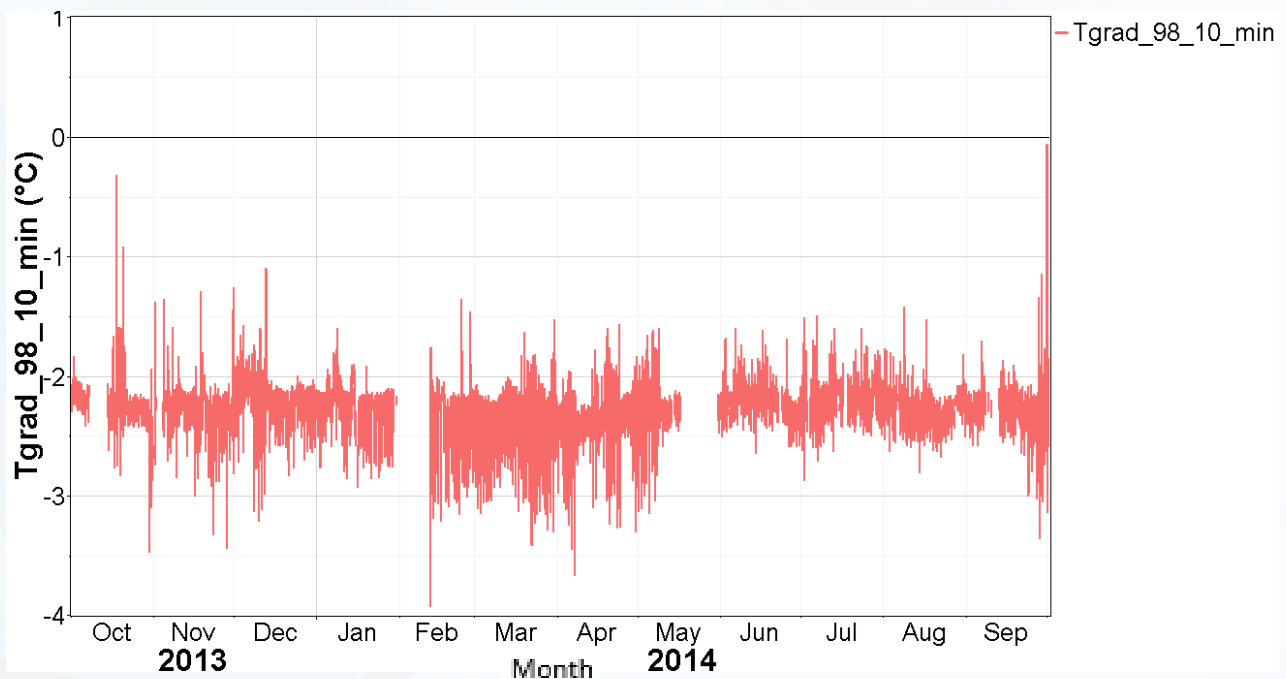


Figure 17: Temperature gradient profile at 98_10 m height

3.3.4 Wind Frequency Distribution

To examine the statistical characteristics of wind speed, data from different height anemometers gathered at Dhanushkodi was used. The wind speed is recorded in 10-min average values at all the levels simultaneously. The distribution of the wind speed data is presented by histogram plots, which is a common method of displaying a year of wind data. It is also known as wind frequency distribution, which shows the percent of time that each wind speed occurs. Figure 18 to 21 show the measured frequency distribution as well as the Weibull distribution for wind speed measurements at 102m, 100m, 80m and 50m respectively. Weibull distribution is commonly used to approximate the wind speed frequency distribution. Similarly, Table 5 depicts the 1 m/s binned percentage frequency distribution at different heights.

Generally, the cut in wind speed of many of the wind turbines is 3-4 m/s and the cut out wind speed is 25 m/s. Hence the operative zone of wind turbines can be considered as 4 m/s – 25 m/s. With this background and as per the analyzed data, it is safe to quote that 90% of time a multi-megawatt modern day turbine can be in the operative zone at Dhanushkodi site.

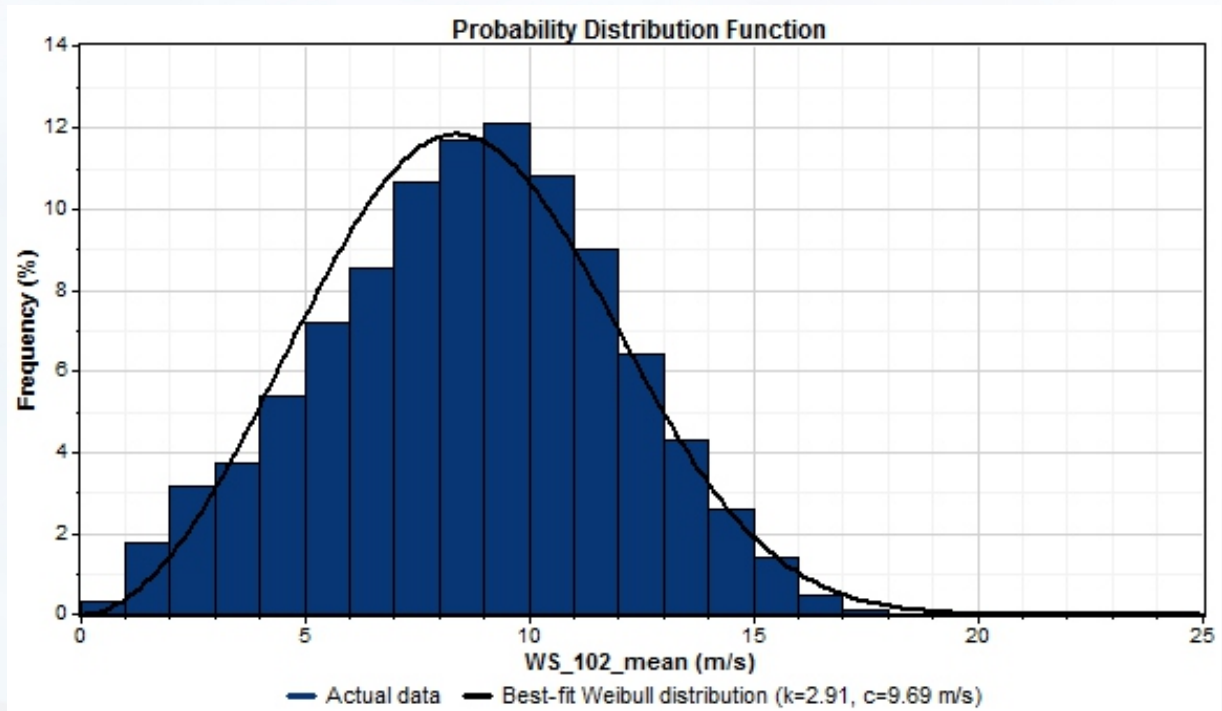


Figure 18: Wind Speed Annual Histogram @ 102m

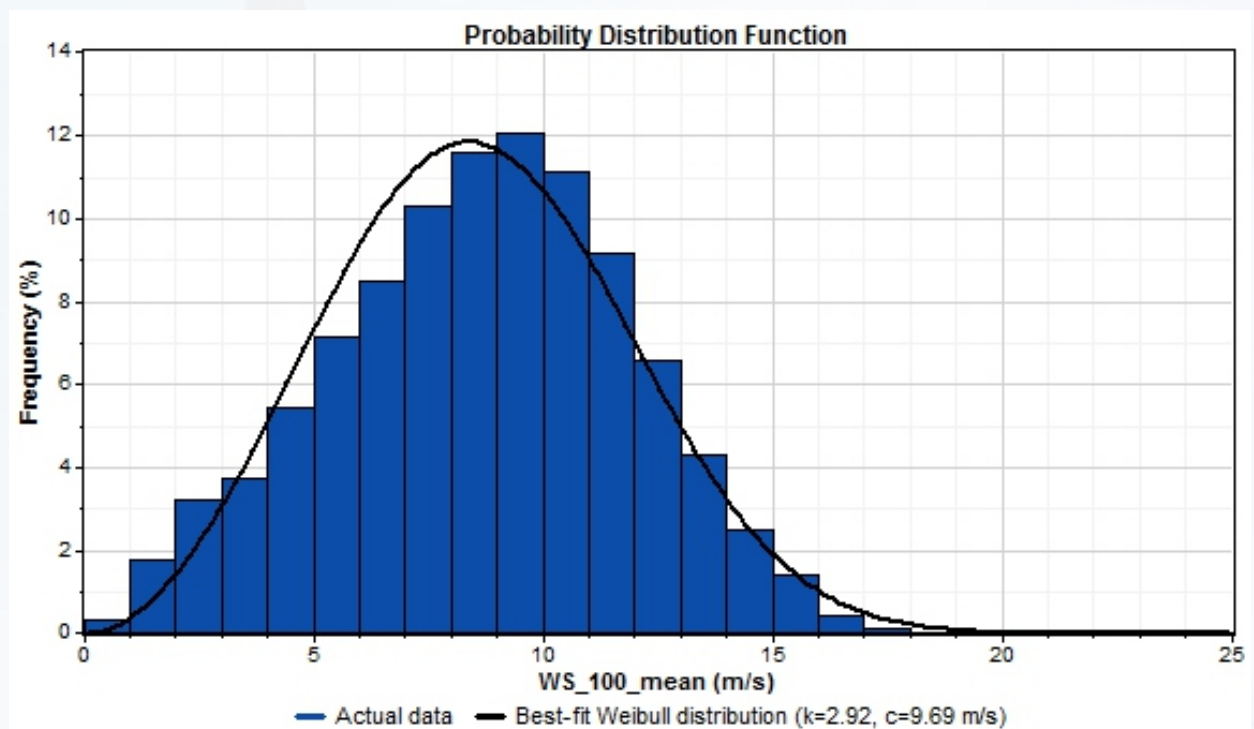


Figure 19: Wind Speed Annual Histogram @ 100m

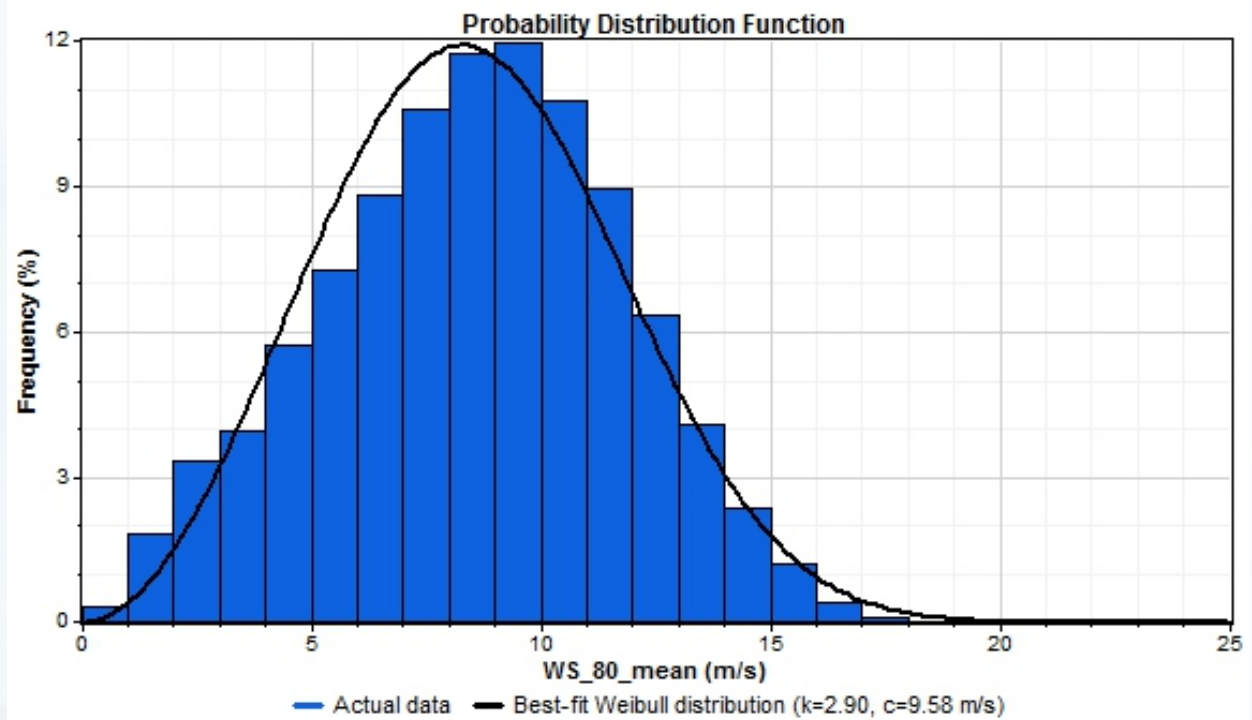


Figure 20: Wind Speed Annual Histogram @ 80m

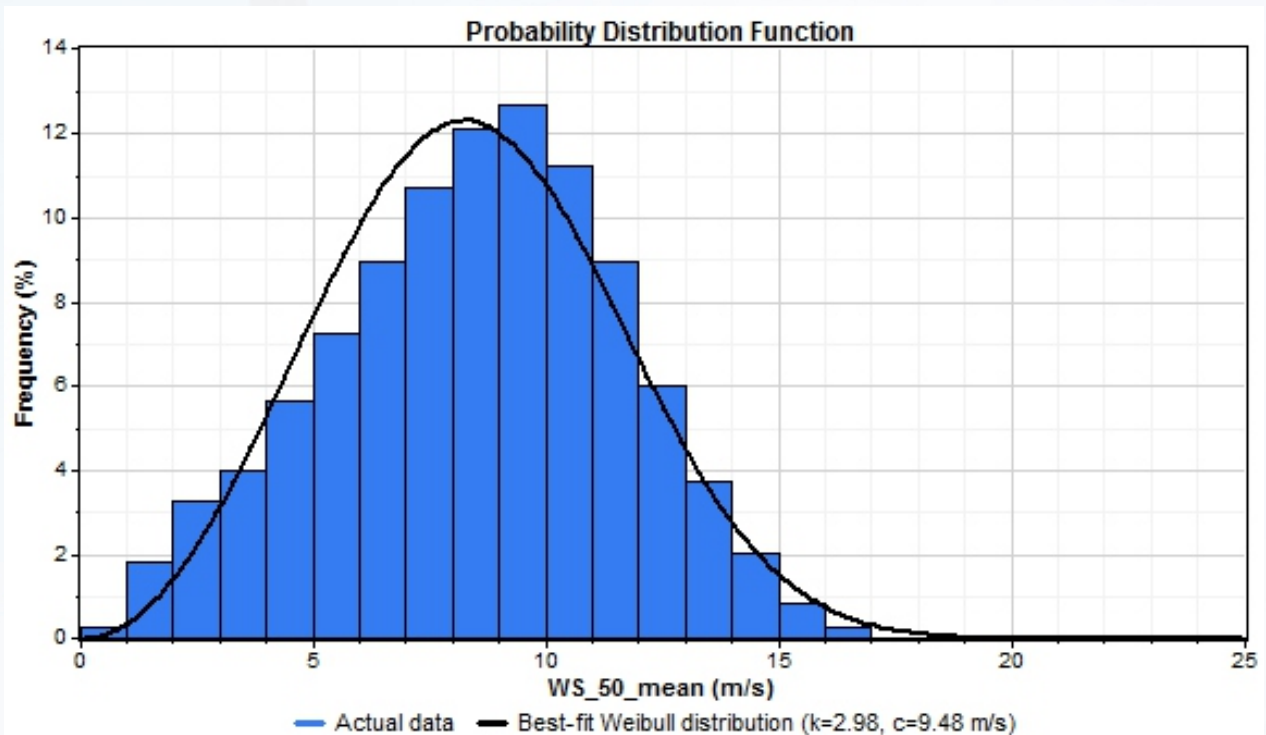


Figure 21: Wind Speed Annual Histogram @ 50m

3.3.5 Wind Shear Profile

The wind shear profile at the site is useful to understand the wind speed variation with height. Figure 22 shows the nature of wind shear at Dhanushkodi site based on the measured data using log law and power law. Table 6 portrays the month-wise power law and log law values.

3.3.6 Turbulence Intensity (TI)

Turbulence Intensity is the basic measure of the turbulence of wind. As per IEC-61400-1 Edition 3, there are three turbulence categories. If the mean turbulence intensity of the site is 0.16 (16%) or more, it comes under category 'A', which represents high turbulence. If the mean turbulence intensity of the site is 0.14 (14%), the turbulence category is 'B'. If the mean turbulence intensity is less than or equal to 0.12 (12%), it represents the turbulence category 'C'.

The optimum turbine classes as per IEC-61400-1 edition 3 with respect to the calculated mean turbulence intensity values at different heights are tabulated in Table 7.

Table 5: Percentage Frequency Distribution Table

Bin (m/s)		Percentage Frequency Distribution (%)			
Lower Point	Upper Point	50m	80m	100m	102m
0	1	0.272	0.312	0.341	0.352
1	2	1.846	1.850	1.797	1.781
2	3	3.298	3.329	3.245	3.185
3	4	3.986	3.955	3.764	3.743
4	5	5.660	5.746	5.457	5.413
5	6	7.272	7.301	7.140	7.230
6	7	8.981	8.830	8.481	8.525
7	8	10.718	10.603	10.327	10.691
8	9	12.089	11.777	11.618	11.703
9	10	12.689	11.965	12.055	12.093
10	11	11.241	10.797	11.159	10.806
11	12	8.967	8.956	9.180	9.023
12	13	6.022	6.355	6.612	6.441
13	14	3.741	4.110	4.290	4.334
14	15	2.053	2.381	2.521	2.599
15	16	0.839	1.209	1.406	1.431
16	17	0.276	0.412	0.460	0.502
17	18	0.044	0.100	0.124	0.124
18	19	0.002	0.010	0.019	0.017
19	20	0.002	0.000	0.002	0.004
20	21	0.000	0.002	0.002	0.000
21	22	0.002	0.002	0.000	0.002
22	23	0.000	0.000	0.002	0.000
23	24	0.000	0.000	0.000	0.000
24	25	0.000	0.000	0.000	0.000

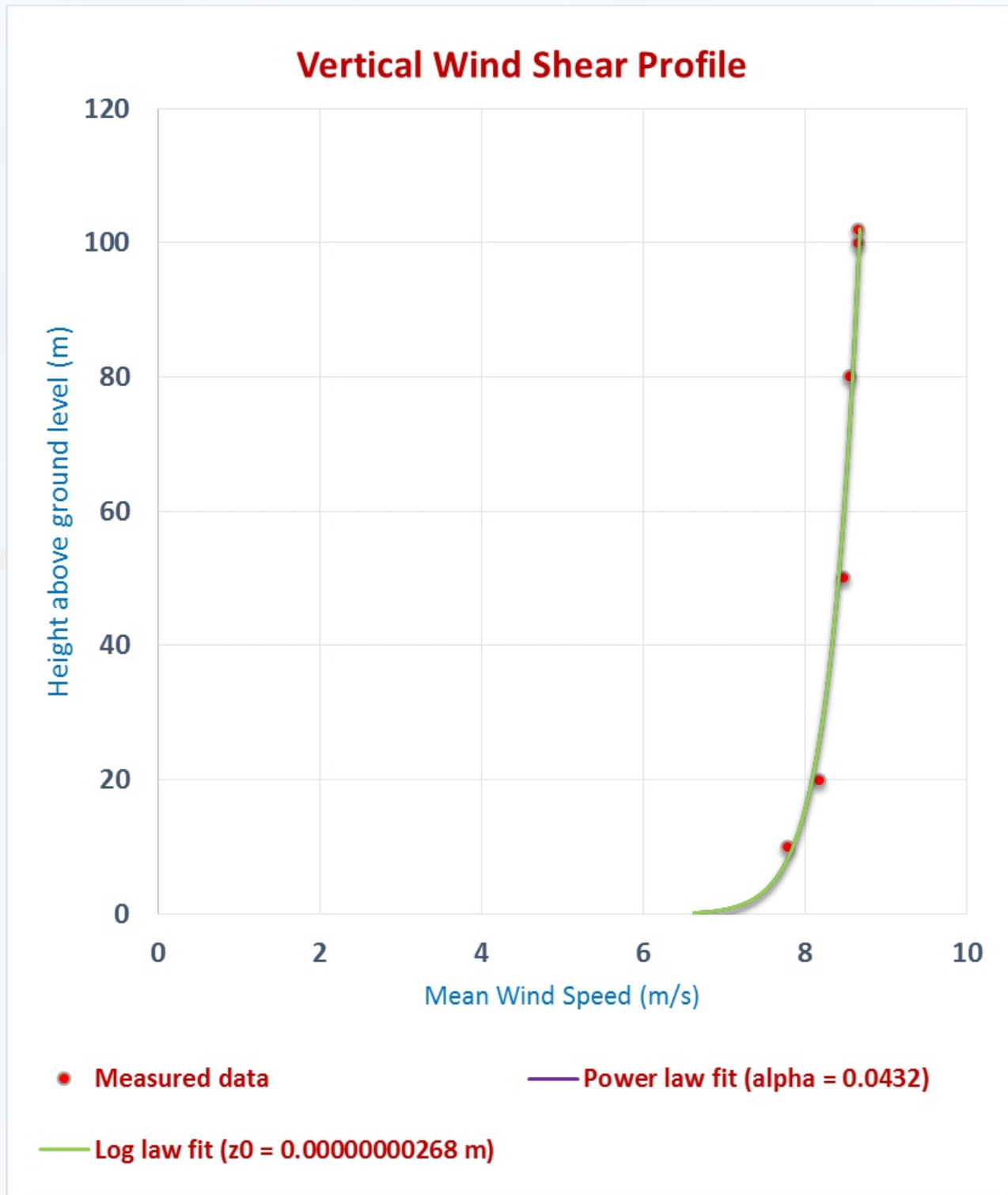


Figure 22: Vertical Wind Shear Profile

Table 6: Vertical Wind Shear Profile Table

Month	Power Law (alpha)	Log Law (z0)
Oct-13	0.042	0.00000000014400
Nov-13	0.0344	0.00000000000066
Dec-13	0.0455	0.00000000081000
Jan-14	0.0457	0.00000000092100
Feb-14	0.0373	0.00000000000633
Mar-14	0.0391	0.00000000002160
Apr-14	0.03	0.00000000000001
May-14	0.0502	0.00000000705000
Jun-14	0.0473	0.00000000204000
Jul-14	0.0497	0.00000000577000
Aug-14	0.0433	0.00000000028500
Sep-14	0.0423	0.00000000017200
Annual	0.0432	0.00000000026800

Table 7: Turbulence Intensity Calculation Table

Height (m)	Mean TI @ 15 m/s	Representative TI @ 15 m/s	IEC 3 Turbulence Category
102m	0.06	0.08	C
100m	0.06	0.08	C
80m	0.06	0.08	C
50m	0.07	0.09	C

3.3.7. Inter-Annual Variation

Inter-annual variation is one of the essential parameters to be considered in any wind power projects and so in an offshore project. It generally details about the wind parameters variation from year to year. Based on the two years measurement performed at Dhanuskodi, a monthly average inter-annual variation graph for 102m anemometer has been plotted as shown in Figure 23. It is clearly seen that April is the least windy month in both the years and the wind speeds vary to a notable extent between the years.

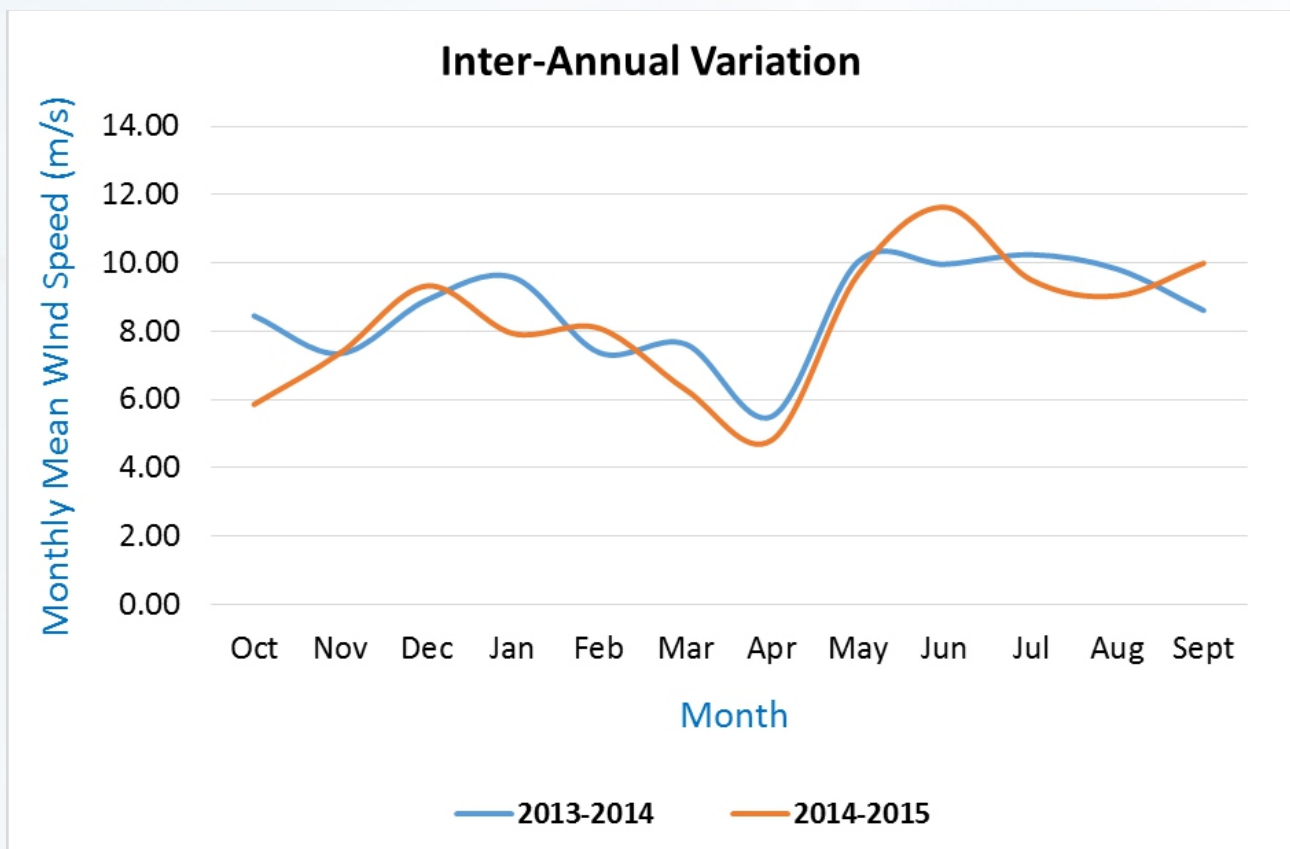


Figure 23: Inter-Annual Variation Graph for Dhanuskodi Measurement at 102m

But interestingly, the annual average wind speed and wind power density (WPD) for both the years seem to be similar (2014-15 (m/s), 2013-14 (m/s)), which is a good indication for assuring the site's bankable wind energy potential. The annual wind speed and WPD comparison graph is shown in Figure 24 for the reference. Continuous measurement in the upcoming years would improve the confidence on the wind speed trend and site's wind energy potential.

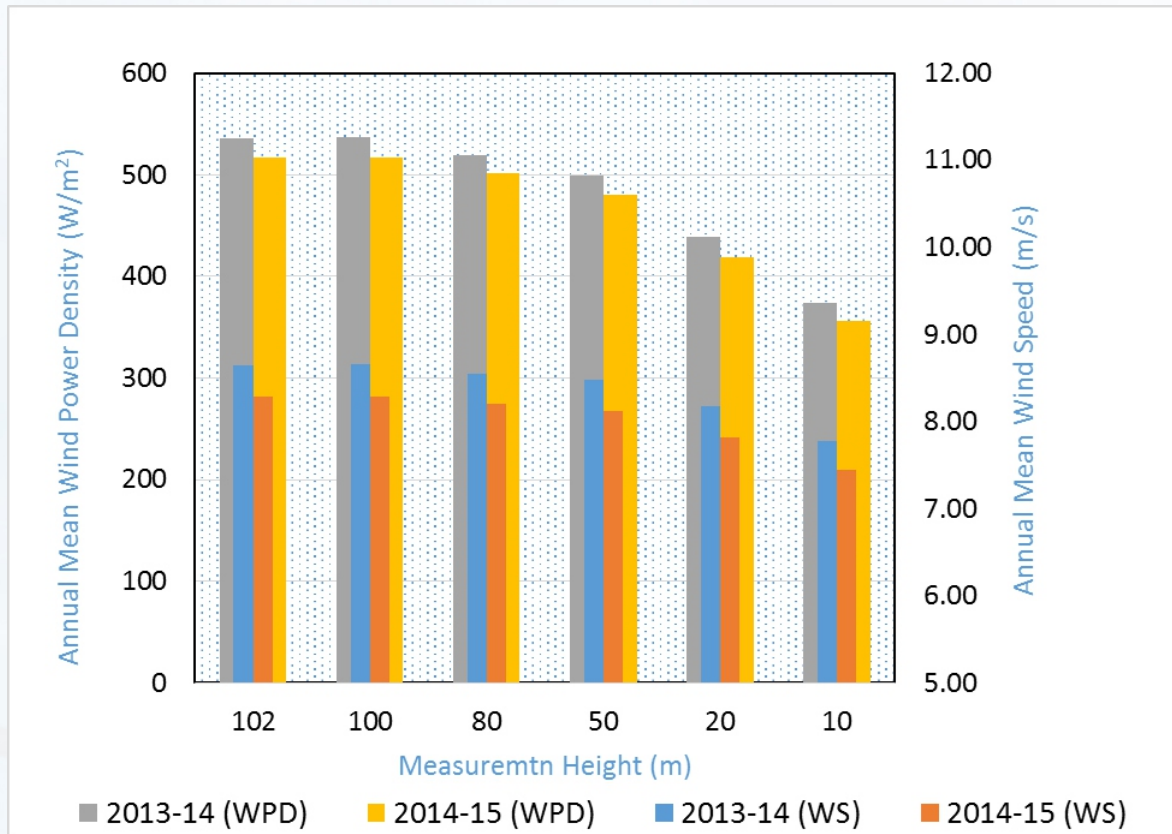


Figure 24: Annual Wind Speed and WPD comparison

4.0 Mast Measurement Vs LIDAR

In order to understand the relationship between the mast measurement and the LIDAR (Light Detection And Ranging) remote sensing instrument, a weeklong LIDAR measurement has been carried out at Dhanuskodi. The Figure 25 depicts the study region.



Figure 25: LIDAR Vs Met. Mast study at Dhanushkodi

The study produced encouraging results that both the mast measurement and LIDAR data were well correlated and also the amplitude variation was also very minimum. Figure 26 & Figure 27 show the time series comparison and the scatter plot drawn between mast data and the LIDAR data. Based on the study, the coefficient of determination between the mast and LIDAR is falling in the range of 97%. The comparison analysis also helped to understand the reliability and accuracy of properly mounted remote sensing instruments, which are generally used to understand the offshore wind climate prior to a full-fledged, costlier offshore met-mast study.

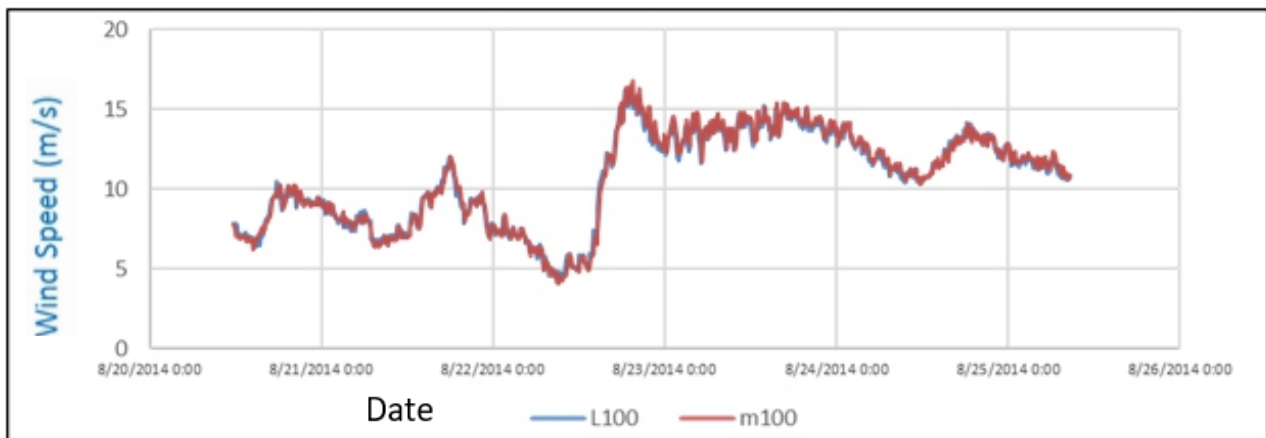


Figure 26: Time Series Comparison between Met. Mast and LIDAR data

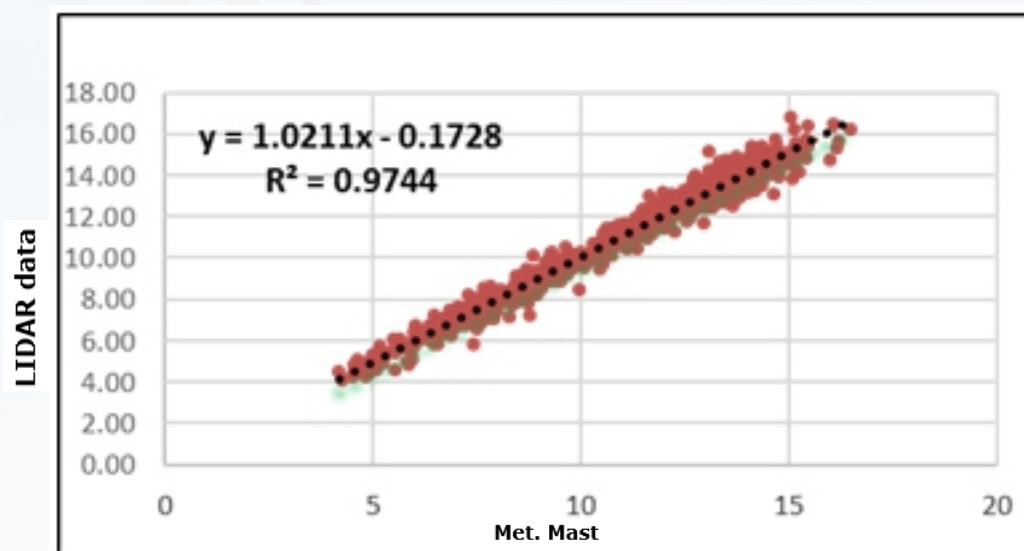


Figure 27: Correlation Plot between Met. Mast and LIDAR data

5.0. Conclusion

The results obtained from the measurement campaign are promising and encouraging. An in-house preliminary energy analysis performed with the help of this data set depicts that there is a good possibility of achieving > 45% Capacity Utilization Factor (%CUF) with the current onshore turbine technology in the Dhanushkodi arrow like strip region. However, with the huge investment for offshore wind projects and inter-annual variations of wind climate into concern, NIWE wish to consider these results as an encouraging indication and prefers to monitor the wind measurement at Dhanushkodi, certainly for a longer period to generate concrete, bankable data sets, wind fetch being predominantly from the ocean, surface.

Reference:

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- [6] <http://www.fowind.in> accessed on 27.11.2015.

AUTHORS PROFILE

Dr. S. GOMATHINAYAGAM, a graduate (Civil Engineering) of Regional Engineering College, Trichirapalli of the Madras University, obtained his post-graduate and doctoral degrees from the IIT-M. After serving as a Project Associate at IIT-M for about one and a half years, and with a brief stint at Best & Crompton design office, he joined Structural Engineering Research Centre (SERC) as Scientist and has risen to the position of Deputy Director and Project Leader of Field Experiments in Wind Engineering. After serving 25 years in solving various multi-disciplinary industrial, consultancy and software development problems at SERC, he has joined as Executive Director in NIWE. He has got UNDP, AUSAID fellowships and has visited several countries.

He shares as a scientist involved for CSIR- Technology Prize for Engineering Software development in 1999, and is one of the members of the team which has won the CSIR Technology Shield for centre of excellence in wind engineering in 2000 and the "A.S. Arya – UOR Disaster Prevention Award" in the year 2001, for their contribution towards cyclone disaster mitigation. He has published over eighty (80) interdisciplinary technical papers in referred national / international journals / conferences / seminars. He has over hundred technical reports to his credit based on the research and consultancy in the areas of power, wind energy, space, railways and Indian Navy involving instrumentation experimental analysis, design and testing and software development.

He is a Life Member and Chartered Engineer of Institution of Engineers (India) and life member of Computer Society of India, Instrument Society of India and Indian Society for Wind Engineering and India Meteorological Society. He has guided several ME, M-Tech, MSc and MCA projects. He served/serves in various awards/selection /promotion/ Academic/ Professional committees including Wind Energy committee of Bureau of Indian Standards. Now, at NIWE as Director General, doing technology management and coordination of research, analysis, design, certification and performance testing, consultancy and human resource development related to Wind Power development in India.

Mr. K. Boopathi is basically a Mechanical Engineer, received Master Degrees (M. Tech) in Energy Engineering at Regional Engineering college, Trichy and Footwear Science & Engineering in Anna University, Chennai. He entered as faculty at Vellore Institute of Technology, Vellore, where he has effectively educated various Mechanical Engineering and Renewable energy subjects for about one year and also he worked in various Renewable Energy Projects such as 10 kW Solar Dish Stirling Engine and 100 kW Biomass Gasification plant.

He has been appointed in January 2003 as Scientist in National Institute of Wind Energy, (NIWE) (formerly Centre for Wind Energy Technology) in which he dedicated to assess the wind resource potential of India at 50 m height and successfully published for public. He also involved in wind monitoring station site selection and installation & commissioning of 50 m mast in various states and various research projects such as wind turbine's noise emission, Blade profile development and Small Wind Turbine Testing, etc.

In 2009, he has been moved to Wind Resource Assessment Unit, NIWE and been actively involved in wind data monitoring, measurement campaign management, data Validation, Site Pre-feasibility studies and Gained an experience in wind resource assessment with various industrial standard software's to estimate the Annual Energy Production, Turbine array layout design, optimization, field Micro siting and prepare bankable report, installation and monitoring of remote-sensing instruments such as LIDAR and SODAR stations and wind atlas preparation of 50 & 80 m height .

In March 2012, he has been championed as Wind Resource Assessment Head and has been leading the unit prosperously. He has been giving consultancy for leading Government organization, Public sectors and Private organizations such as Wind Farm design and development, Analysis of existing wind farm operations, Technical due diligence in virtuosity with international standards, DPRs (Detailed Project Report) preparation, etc. He has also been involving in various research projects such as offshore wind profile measurement, study on Wake behind the wind turbine and wind power forecasting, etc. In May 2015 successfully launched wind power forecasting project for the state of Tamilnadu and the project has been successfully progressing in the state. In September 2015 successfully prepared and

released 100 m height wind potential map with 500 m resolution and in 2016 August prepared & released 20 m height wind speed map for small wind energy sectors.

His current responsibilities include preparation of wind atlas at 120 m height, offshore wind profile measurement activities in various locations and coordination with FOWIND offshore project, extending wind power forecasting services to other states, prefeasibility study, DPR preparation, wind resource and energy assessments, training, analyzing wind data and performing correlation between wind measurements systems and long term Data, Provide energy resource assessments and production calculations, Optimize turbine layouts according to resources and constraints and carrying out research works in wind resource assessment.

Shri. J. Bastin is working as Asstistant Director(Technical) in Wind Resource Assessment Unit of NIWE since 2013. Basically an Electronics Engineer, he obtained his Masters in Energy Systems from University of Petroleum and Energy Studies (UPES), Dehradun. He has 5 years of experience in various facets of WRA unit include site selection, data analysis, Micrositing, Technical Due Diligence, etc., Currently he is being involved in wind potential mapping and other R&D related activities in the unit.

Disclaimer

All the analysis, results and conclusion are based on the measurement carried out at Dhanuskodi since October 2013. The latest mathematical tools have been employed while computing the results. The results are published for the public interest. National Institute of Wind Energy (NIWE), Chennai makes no warranty express or implied, or assumes any legal liability or responsibility for the users' application or use findings of the results from the analysis.



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