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Offshore Wind Potential of East Coast, India

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Abstract: ***Due to rapid advancement in technology, the usage of wind energy has increased in parts of globe. Investigation of offshore wind energy potential is done in the present paper; in East Coast of India. The wind speed and wind direction hourly data for a period of 10 years between 2006 and 2016 is used for the analysis for plotting the wind rose diagram. The paper presents Weibull factors based on daily variations analysis of wind data in 12 regions of West Bengal, Odisha, Andhra Pradesh and Tamil Nadu. The energy production is studied using the Suzlon S97 turbine. The total energy that can be produced is expected to be 49.31 GW/yr, which can overcome 9.27 percent of the power deficit in the Eastern states of India. ArcGis is used to depict the estimated power generation and capacity factor of the study areas.***

Keywords: Offshore wind; wind rose; Weibull factor; Suzlon S97 turbine; East Coast, India

1. Introduction

Energy has become for inhabitants of the planet an essential entity, of technological advances and life style, which is materialistic in this era. In modern world sorrowfully, a million people in various parts of world, have no electricity access. The major challenge is meeting this growing energy demand while equally reducing the threat of climate change urgently, at the same time. Of the various green energy sources, the usage of wind energy has increased due to rapid advancement, in different parts of the globe.

Wind is ultimately a solar source, which is inexhaustible, clean and free as an energy source. It is the energy source, which is fastest growing in the world and can power houses and industries with electricity in renewable form. Wind turbines do not do consumption of fuels in its operation. Emissions of particulates, Sulphur dioxide, carbon dioxide, & any other type of air pollution, do not produce.

The kinetic energy of the wind harnesses energy. In the atmosphere the total annual kinetic energy of air movement is estimated to be about 0.2% of the solar energy received by the earth or about 3·1015 kW [6]. Theoretically, the technically usable potential maximum is estimated to be around 34.5% of current consumption of world total energy or 30·1012 kWh/yr. The wind speed at 25.5 kmh^{-1} gives power about 200Wm^{-2} of windmill area swept.

Offshore wind resources are stronger, abundant and blow constantly than on land wind resources. Less wear and tear on the components of turbine and more electricity generation per meter square of rotor area swept is found in winds which are high and steady. Offshore wind turbines are used by many countries to harness this energy resource found over the oceans. Power is generated in these turbines much closer to higher value coastal load centers. Reduction of visual intrusion and noise emissions at enough distance from the coast, are the benefits of offshore turbines. In addition, larger wind turbines increase the overall installed capacity per unit area.

The K.E. (kinetic energy) of wind gives power P that is proportional to 0.5 (mass * velocity^2), i.e.the air passing mass through area (A in a unit time with wind velocity v, given by the equation:

$$P = [1/2(\rho Av)v^2] = [1/2\rho Av^3]$$

where, v is wind velocity, ρ is mass density and ρAv is air mass flow rate[6].

For the initial indicator the annual average wind speed at a location is useful for the wind resource value. Offshore wind speeds must be considered at heights above 80m. If the data collected is at three different height, it is calculated to 80m according to the following equation:

$$v = v_o[h/h_o]^k$$

where, v is wind speed (m/s), h is measured height of wind speed (m), v_o is the anemometer height wind speed h_o (m/s), h_o is anemometer height (50m) and k is the height exponent (0.143)[5].

Speed of wind probability is calculated by Weibull curve & defined by the shape factor (K) and average wind speed. "Bins" of 1 m/s in width of wind speed are broken down to facilitate piece-wise integration[8]. The Weibull wind speed probability (f) is multiplied by instantaneous wind turbine power(W) for each wind speed bin. This product, Net W contributed by speeds of wind in that bin is the contribution to average power output of turbine[9]. Weibull curve distribution for the wind data is the best possible fit. The relevant formulae is as follows:

$$P(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right]$$

where, P(v) is the probability of the wind speed measured, (v), (c) is the Weibull scale parameter in (m/s) and (k) is Weibull shape parameter which is (dimensionless). Cv gives the integral of the Weibull probability density functions

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called as the cumulative frequency distribution which is given by:

$$C(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right]$$

2. Motivation and Objectives

Direct impact on requirements of energy is due to Population growth. With respect to India, there were 1.159 billion consumers of electricity in 2007 year, which then reached to 1.326 billion in 2016, an increase of nearly 28.5%. The consumers' number in different years as shown in 0. linear consumer rate of growth from year to year is observed. The number of consumers from year 2007 to 2016, increased by 30%, respectively. The energy growth reached 97,050 GW in 2007 from 122,944 GW in 2015.

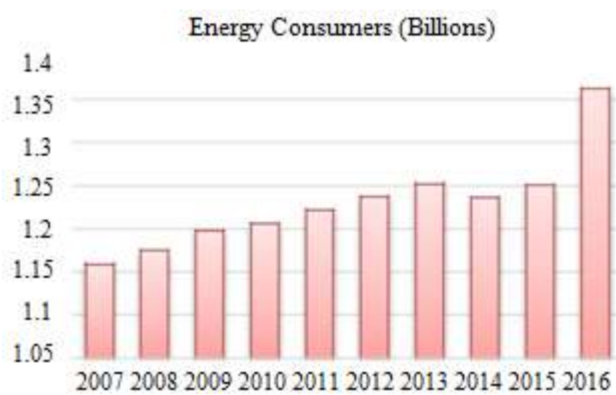

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Figure 1: Growth inconsumer'snumber with respect to per year

Offshore Wind energy growth from 5 to 80 GW by 2015 has been expected as countries in North America, Europe & Asia heavily support offshore industry. Cumulative growth of wind power has experienced over the last few years. At the same time, strong turbine deployment activity and increase in overall capacity is expected at healthy pace. Top companies of Wind turbines like, Vestas, Siemens, Gamesa, already have started work in the new potential market on offshore development activities. Offshore wind energy production costs are expected to reduce as the technology and industry matures.

As shown in the0. the winter wind has average velocity of 4 to 6 m/s where as in 0in the summer the wind velocity is about 8 to 10m/s, surrounding the east coast, India.

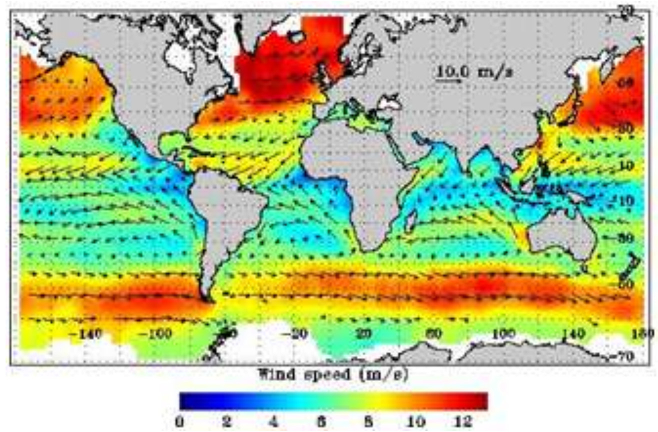

Figure 2: Velocity of wind during winter season *(Source: SEOS, UNESCO)*

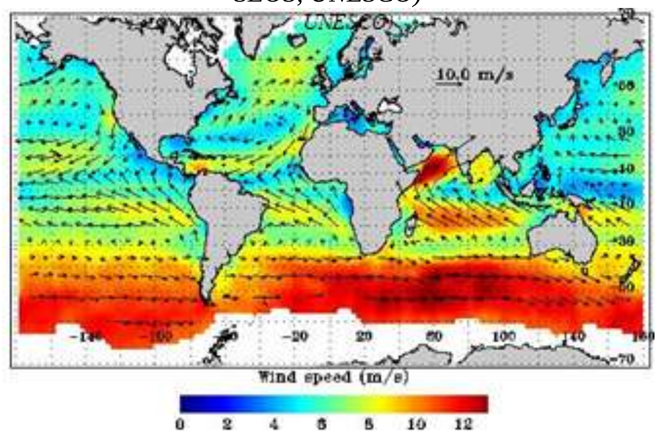

Figure 3: Velocity of wind during summer season (Source: SEOS, UNESCO)

Hence, the growing demand for energy, existing speed of wind and direction of wind data at different locations in the east coast of the country and use of energy sources that are green awareness, are few of the factors that motivate for conducting wind analysis at east coast in the country. The objectives of this study include different wind speed bins according to wind availability, Weibull distribution, capacity factor and energy production determination.

3. Site and Data Description

The study will conducted for West Bengal, Odisha, Andhra Pradesh& Tamil Nadu India, based on compilation of data for various locations from various sources as shown in **Error! Reference source not found.**. The State of West Bengal confined roughly within 30° 29' 52" N, 77° 55' 18" E for Odisha 20.1500° N, 85.5000° E & for Andhra Pradesh 16.5° N, 80.6° E. & Tamil Nadu 13.0900° N, 80.270° E. These states lie on the shore of Bay of Bengal India. They are where the Eastern Ghat ranges meet into the Eastern hill complex situated on a tableland. Total length of east coast is 3,287 km^2.

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Table 1: Geographical Location of the studied areas

State / Area	Latitude	Longitude
West Bengal		
Mandarmani	21.6681^{O}N	87.7025^{O}E
Digha	21.6266^{O}N	87.5074^{O}E
Odisha		
Paradip	20.3166^{O}N	86.6114^{O}E
Puri	19.8510^{O}N	85.7256^{O}E
Gopalpur	19.2647^{O}N	84.8620^{O}E
Andhra Pradesh		
Vishakhapatnam	17.6868^{O}N	83.2185^{O}E
Kakinada	16.9891^{O}N	82.2475^{O}E
Manchallipatnam	16.1905^{O}N	81.1362^{O}E
Ongole	15.5057^{O}N	80.0499^{O}E
Tamilnadu		
Chennai	13.0827^{O}N	80.2707^{O}E
Cuddalore	11.7447^{O}N	79.7680^{O}E
Nagapattinam	10.7656^{O}N	79.8424^{O}E

4. Result and Discussion

The parameters measured included wind direction and wind speed at 50 m above the surface of the ground. A period of 10 years from 2005 to Feb 2016 covered in the included data. The availability of wind in terms of frequency distribution, long term mean wind speed diurnal and annual variation, energy calculations using Suzlon S97 wind turbine of 2.1 MW rated power and capacity factor estimation. Lastly, discussion of the energy output with wind velocity at 80 m calculated by the power law and hub height is carried out.

Windrose and Weibull

For constructing, the wind rose and analyzing the frequency distribution, wind direction and all wind speed hourly average values were used & the wind rose diagram which resulted for all the selected areas using Windographer are shown in the **Error! Reference source not found.**. The major wind direction was southwest from Digha to Kakinada. The highest wind frequency distribution was observed at Ongole, Andhra Pradesh. Weibull distribution for the selected areas was also calculated which are tabulated in the 0. Weibull shape factor varies from 1 to 4. The wind is more consistent as the value approaches 4. Vishakhapatam onwards the velocity of wind seems to be more consistent from the obtained results.

Table 2: Wind Direction and Weibull factors

Coast	*Dominant Wind Direction*	*Weibull Factors*	
		k	*c (m/s)*
Mandarmani	South West	2.17	5.68
Digha	South West	2.16	5.41
Paradip	South West	2.17	6.33
Puri	South West	2.24	5.78
Gopalpur	South West	2.24	5.78
Vishakhapatnam	South West	2.50	6.42
Kakinada	South West	2.59	6.42
Manchallipatnam	South	2.83	6.58
Ongole	West	2.56	6.07
Chennai	North East	2.89	6.42
Cuddalore	South West	3.05	6.20
Nagapattinam	South West	3.14	7.02

Wind Energy Generation Analysis

For the above locations, the average annual wind speeds over last 10 years was calculated, as indicated in 0. Along with the capacity factor for each location selected. The generation of rated power of each location was obtained from the power equation using the values of selected turbine SUZLON S97 at the annual mean speed of wind of each location. The power curve of the turbine is shown in **Error! Reference source not found.**. Diameter of rotor was 97 m, air density as 1.221 kg/m3 and power law exponent as 0.143. Offshore wind turbines are suitable at wind velocities of 6 m/s and more. Andhra Pradesh and Tamil Nadu are suitable for offshore wind farms as tabulated in 0.

Table 3: Capacity Factor and Power Calculation

Coast	Velocity m/s (50m)	Velocity m/s(80m)	Power (kW/yr)	Capacity Factor
Mandarmani	5.04	5.38776	3,422,098	18.6
Digha	4.8	5.1312	3,032,245	16.5
Paradip	5.62	6.00778	4,440,173	24.1
Puri	5.13	5.48397	3,541,672	19.3
Gopalpur	5.13	5.48397	3,541,672	19.3
Vishakhapatnam	5.71	6.10399	4,461,920	24.3
Kakinada	5.71	6.10399	4,424,180	24
Manchallipatnam	5.87	6.27503	4,655,410	25.3
Ongole	5.4	5.7726	3,855,763	21
Chennai	5.89	6.29641	4,651,481	25.3
Cuddalore	5.54	5.92226	3,895,320	21.2
Nagapattinam	6.29	6.72401	5,392,741	29.3
TOTAL			49,314,675	

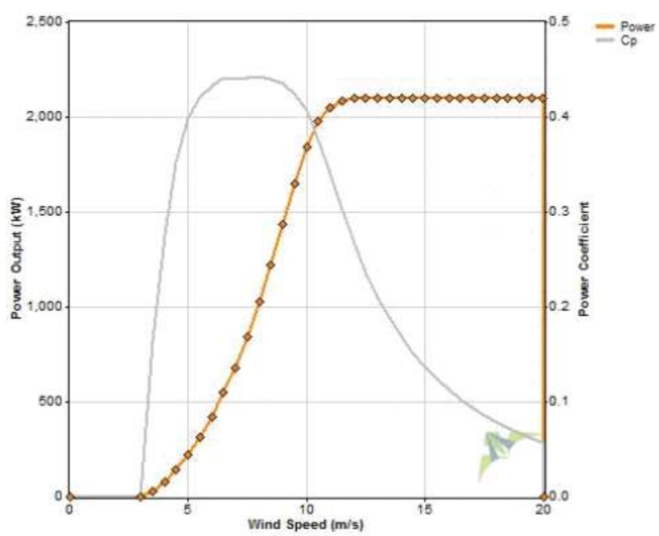

Figure 4: Power curve of Suzlon S97

Table 4: Estimated Power Generation State wise

State	Power (GW/yr)
West Bengal	6.45
Odisha	11.52
Andhra Pradesh	17.39
Tamil Nadu	13.93
TOTAL	49.314

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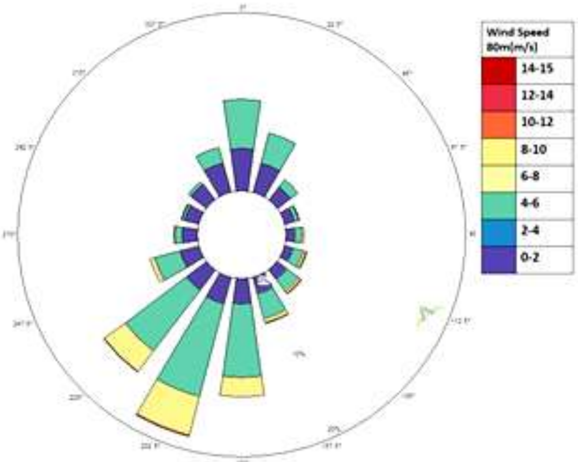
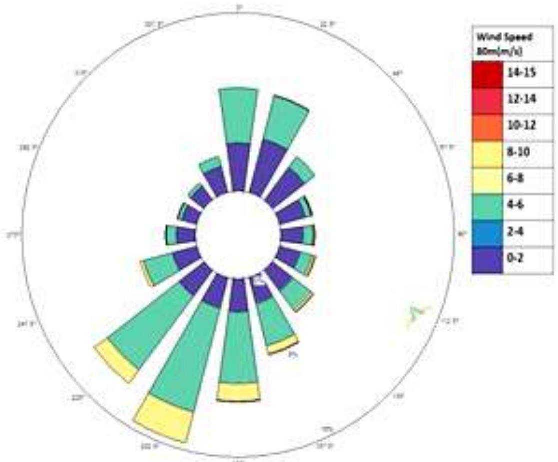
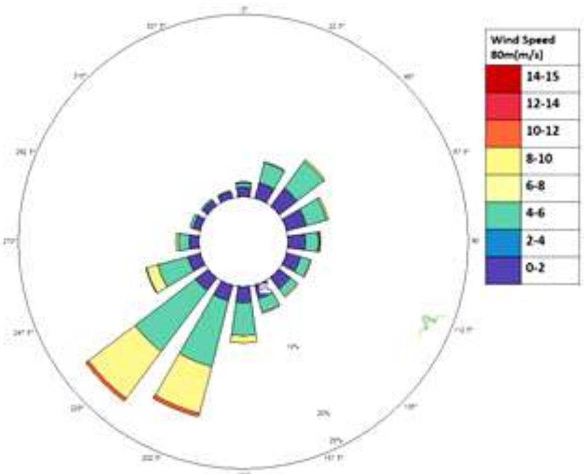


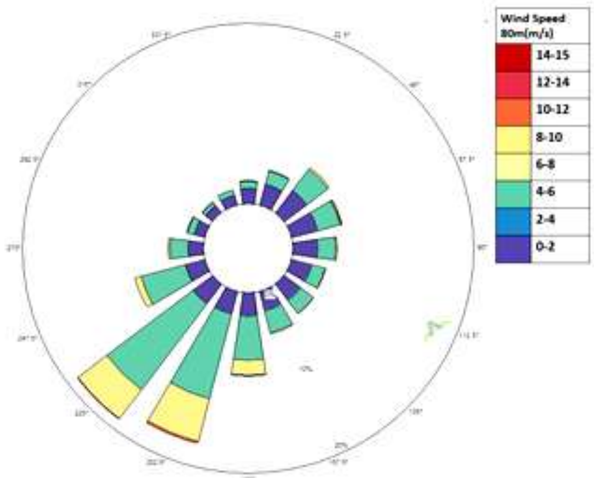
Mandarmani, WEST BENGAL



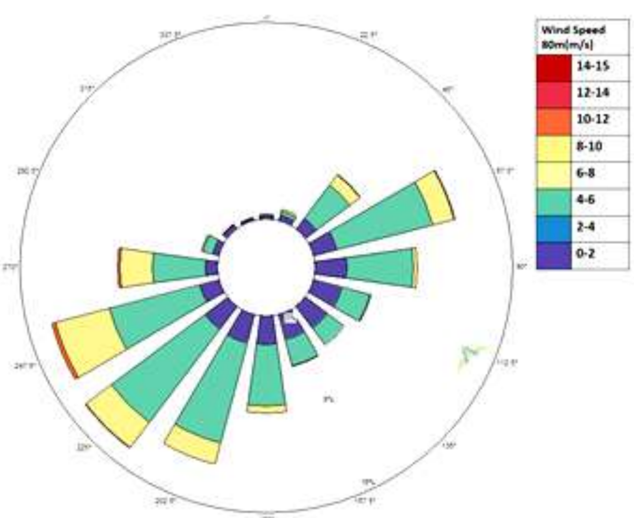
Digha, WEST BENGAL



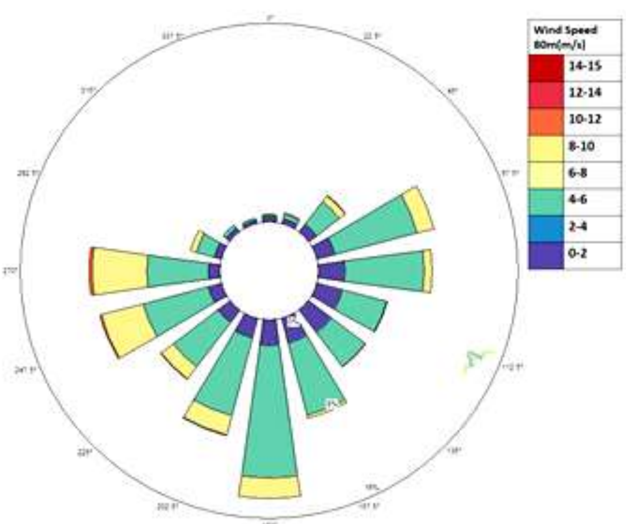
Paradip, ODISHA



Puri, ODISHA



Kakinada, ANDHRA PRADESH



Manchalipatnam, ANDHRA PRADESH

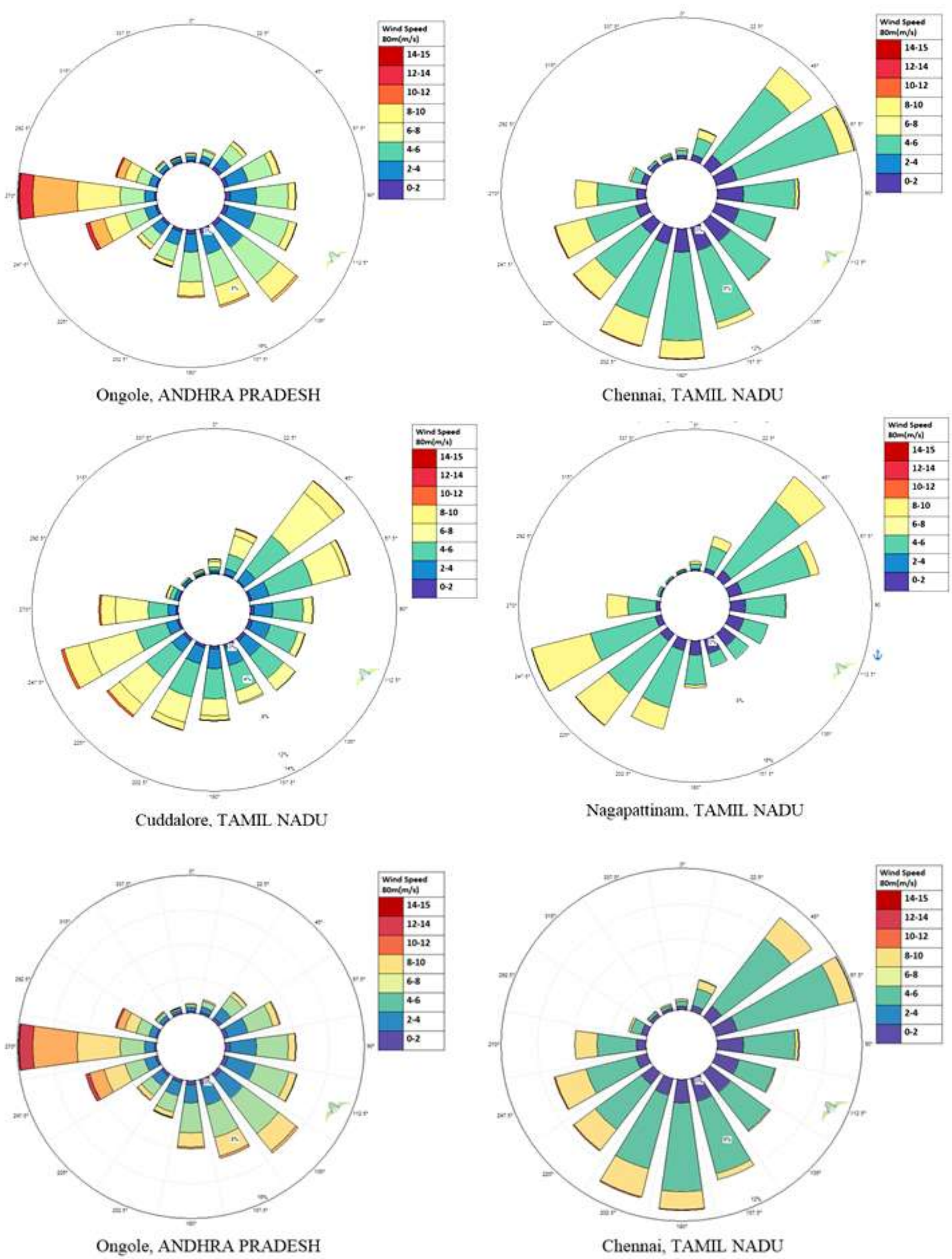


Figure 5: Wind rose diagram representing wind direction and wind speed of the study areas

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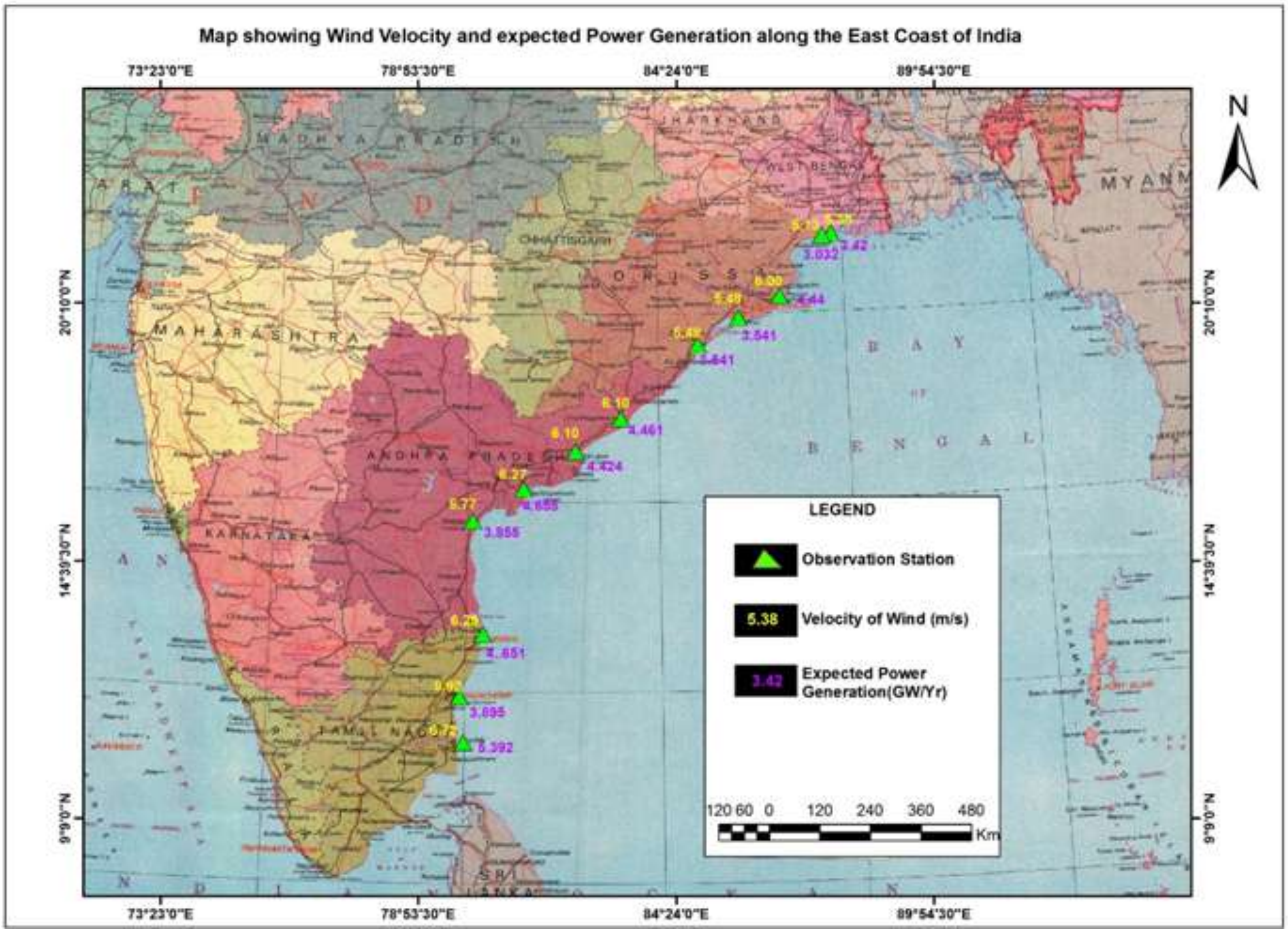

Figure 6: Representation of Expected power generation and mean offshore wind velocity of the areas studied

The peak deficit power supply is estimated to be 1389 MW in the four eastern coast states according to the Load Generation Balance Report 2016-17. The estimated offshore wind potential can overcome 9.72 percent of the power deficit. Offshore power potential for the 12 selected points have been shown in 0along with the capacity factor using ArcGis 9.3.

5. Conclusion

Characteristics of wind have been analyzed for the East Coast of India based on measured datasource of over 10-year period (2006-2016). The wind rose diagram reveal that the prominent wind direction of the east coast as South West, which goes towards north as it comes to the southern coast. The wind speed ranges from 5 to 7 m/s at 80m hub height, which can produce ample amount of energy. Wind speed and the capacity factor was found more in Andhra Pradesh. Hence, it has potential for setting up an offshore wind farm. The total expected energy estimated from the investigated area i.e. Andhra Pradesh is 17.39 GW/yr. This value could increase at higher hub heights of 100m and 120m.With increased hub heights, Tamil Nadu's upper coast could also be a potential offshore wind farm. Power deficit of over 9.72 of the east coast states could be overcome by setting up offshore windfarms in the eastern coast of India.

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