

Site selection for offshore wind farms along the Indian coast

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Received 30 September 2013; revised 13 November 2013

This study deals with the location of the potential sites for offshore wind farms and also deals with the feasibility of installing offshore wind farms through scientific examination along the coast of India. Offshore wind energy is almost unexplored along the Indian coast. Potential and feasible regions need to be found and studied in detail. In this regard, few of the essential primary parameters such as bathymetry, wind velocity, proximity to the coast, ports, harbours, marine protected areas and marine sanctuaries were considered. Suitable sites for offshore wind farms were demarcated in a GIS environment. Weekly climatology (1999-2009) of wind speed was used to explore the seasonal wind potential. GIS analysis has brought out potential wind farms regions of 32,000 km² in north east Arabian Sea (Off Mumbai and Off Ratnagiri) where bathymetry is in the range of 20 m to 75 m. Wind velocity ranges between 1.9 m/s to 10.2 m/s in these regions. The second potential site has been identified at off Mangalore with 6490 km². The third prospective site is at Off Hooghly estuary.

[Keywords: Offshore wind farms, wind velocity, west coast of India, clean energy, GIS.]

Introduction

The world energy demand has been ever increasing. Energy sector has seen many changes over time due to introduction of new technologies. Conventional sources of energy have ruled the energy market thus far. But due to issues like extinction of fuels and protection of the environment, many countries have considered renewable energy resources as the primary energy source in the last two decades. Share of renewable energy resources has been increasing over time as new technologies are discovered. Wind, solar, biomass and geothermal energy form only 0.7% of the total share of global energy consumption. But the overall installations of wind energy turbines have been increasing since the 90's. Due to the advancement of research and technology, the wind power capacity has been increasing exponentially. That is because wind energy is one of the cleanest and most ubiquitous resources in the world, which humans have used for thousands of years¹.

As the population in India is rapidly growing, the demand for energy is increasing. As a result, India's installed power generation capacity has increased from 1.4 GW in 1947 to 201.6 GW in 2010². Power

generation using wind energy in northwest Karnataka, India was studied using wind farms³. About 53 percent of electric power in India is generated from coal and lignite based steam thermal plants which contribute a lot to air pollution⁴. Therefore, the need of the hour is a cleaner sustainable renewable source of energy, in which wind power can play an important role. Wind energy is also clean energy because wind turbines produce no pollution while operating. India has been playing an important role in world's energy market. As far as wind power is concerned, India holds fifth place in the world for a total wind power capacity of 13.2GW⁵.

Land-based wind energy has been harnessed for decades on industrial scale and is a proven technology. Wind is one of the renewable energy technologies that rely on a free and naturally abundant fuel source. It can serve in the economic development of the country due to direct and indirect jobs. It serves to the global cause of addressing climate change by reducing the greenhouse gas (GHG) emissions. It also avoids the import of gallons of oil for power production. Though the manufacturing and installation of the turbines themselves do result in emissions, an offshore wind turbine normally takes 3 months of generating zero-emission energy to offset

the greenhouse gases emitted in manufacturing the turbine. Wind turbines usually have an operational lifetime of around 20 years and wind turbine generates a significant amount of net emissions of free energy in its lifetime. For example, a 3.6 MW turbine can produce up to 6, 22,944 Megawatt-hour (MWh) of net-emissions-free energy in its lifetime, which is equivalent to 76.5 tons of coal and 281 tons of CO₂ emissions. A 420 MW wind power plant, over its lifetime, can generate the same amount of electricity as 9000 tons of coal, or 33 million tons of CO₂ emissions⁶. Unlike coal-powered generators, 90-100 percent of all material from wind turbines can be reused⁷. Offshore wind farms have many advantages over onshore wind farms. Offshore wind potential is considered to be higher than onshore because offshore winds are stronger and more consistent.

The advantages and challenges of offshore wind platforms are briefly explained (Table 1).

Materials and Methods

Area: Greater area available for setting up large projects is one of the primary advantages of moving towards offshore projects.

Wind Speed: Wind speeds are significantly higher at offshore regions. A global study of wind patterns found that offshore wind speeds are averaged 90% higher than onshore wind speeds⁸.

Turbulence: Wind is less turbulent at sea than over land which results in lower mechanical fatigue load and thus longer lifetime of the turbines.

Visual Impact: Off shore wind farms are located far from land and they have less visual impact which helps with public acceptance issues. As they come much less into human contact, people do not need to deal with the noise pollution and eye sore that turbines cause for some. Farmers complain at times that the whirring noise of the turbines scare their livestock while others simply do not like the sight of the turbines. Thus, by moving off land, the sounds and images of the turbines are nearly unnoticeable. Fishes and fishermen are least disturbed with proper

placement of turbines.

Challenges: Eventhough wind is available everywhere, harnessing that wind for electricity requires some thresholds for wind speeds. Lack of geographic and geologic locations, suitable for installing wind turbines and transmitting power to where is needed. The challenges that come on the way of setting up offshore wind farms are:

Cost: The capital cost of offshore wind farms projects is higher compared to onshore wind power projects. The average capital expenditure is double mainly because of many bottlenecks. The cost in India might be higher because of the absence of Turbine Installation Vessels (TIVs), construction support vessels, lack of sub-structure manufacturers, and lack of trained man power etc⁹.

Technology: Offshore wind projects also require different transmission lines for feeding the output to the grid. Since salt water is a conductor of electricity, submarine transmission cables must be heavily insulated to prevent any leakage. Windy areas have rough waters and rocky coastlines that quickly wear out transmission lines.

Scientific data: There are many parameters used for assessing the feasibility of offshore wind farms. Data for many of those parameters might not be available. The design process involves an initial site selection followed by an assessment of external conditions, selection of wind turbine size, subsurface investigation, assessment of geo-hazards, foundation and support structure selection, developing design load cases, and performing geotechnical and structural analyses.

Wind turbines are generally mass produced and available in four predefined classes based on wind speed. Consequently, the designer simply selects one of the predefined turbine classes that may apply to the wind farm site. Water depth, seabed conditions, sea state statistics (wave heights and current velocities), etc., may vary widely between sites, hence, the use of a generic support structure concept is not feasible. Therefore, the tower, substructure and foundation, are designed for site specific conditions. The foundation system is selected based on several factors such as the level of design loads, depth of water at the site, the site geology and potential impact to the marine environment. As larger, customized wind turbines are developed, they will require an integrated analytical model of the turbine, support structure and foundation system and rigorous analyses with site specific wind and wave regimes.

Table 1—Advantages and challenges of offshore wind farms over onshore wind farms

Advantages	Challenges
Area	Cost
Wind Speed	Technology
Turbulence	Data
Visual Impact	

Study area

India has a very long coastline of 7500 km including the island territories and also has an EEZ of 2.172 million Km². It is surrounded by Arabian Sea on the west, Indian Ocean in the south and the Bay of Bengal in the East. India has high wind potential on the shores and also on offshore. This study attempts to find out the potential sites for the offshore wind farms within India's EEZ region (Fig. 1).

Essential primary parameters such as bathymetry, wind velocity, proximity to the coast, ports, harbours, marine protected areas, and marine sanctuary which are used in assessing the feasibility of offshore wind farm using the GIS environment. Weekly climatology of QuickSCAT wind speed data with resolution 0.25 x 0.25 degree was used for the period 1999-2009 to explore the seasonal wind potential.

Bathymetry:

Bathymetry, the water depth of the sea or the ocean, is an essential parameter because it decides the primary cost of the tower. Installation of wind turbines beyond a certain depth is not feasible because that might lead to hefty structures leading to increase in cost. The feasible depth for turbine installation is 15-75 m¹⁰. Beyond 75 m, it becomes difficult and leads to unnecessary expenditure. The below major intervals of bathymetry are used in this study (Fig. 2).

- a) 0 m - 24.9 m
- b) -25 m - 49.9 m
- c) -50 m -74.9 m
- d) -75 m and above

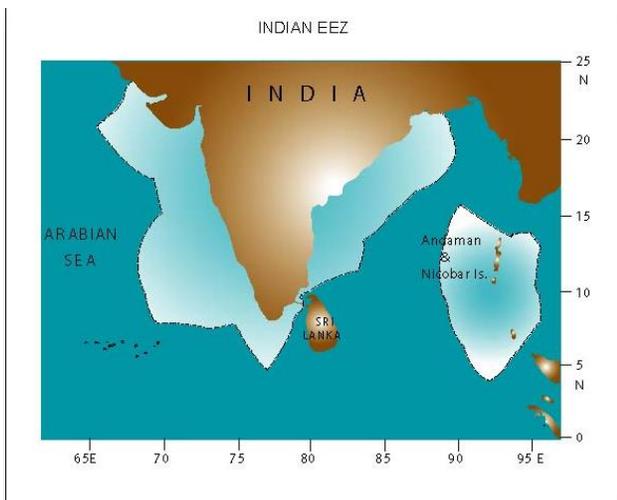


Fig. 1—Study region, the dashed line represents the Exclusive Economic Zone (EEZ); (Courtesy: www.niobioinformatics.in)

Wind speed:

Wind speed is an important parameter which decides the feasibility of a particular site. There are certain thresholds which are to be followed for generating optimum power. Minimum wind speed of 5 – 5.5 m/s is considered as threshold for any wind energy development in onshore and higher wind speed has to be considered for offshore in order to make the exploitation economically viable¹¹. Averaged wind velocity for 52 weeks over the study region has been estimated to find the overall idea of wind availability (Fig. 3).

Proximity to the coast, ports, harbours:

Due to the installation of the wind farms, there could be danger of collisions between vessels and offshore wind towers. As a result of collision, there would be chance of pollution through oil spills or chemical spills. Also, there could be damage to the HV station because this could result in long idle period for the wind farm with extensive loss of potential energy production. Collision during the construction or maintenance activities could result in injuries or even dead among



Fig. 2—Bathymetry Surrounding the Indian subcontinent (Data Source: GEBCO)

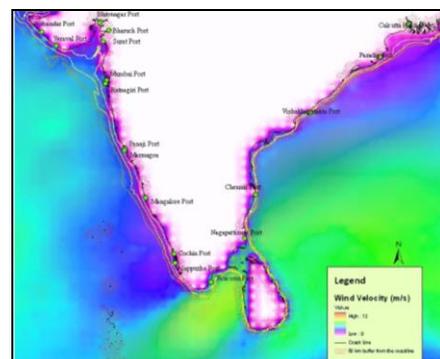


Fig. 3—Wind Velocity (m/s) (Averaged over 52 weeks)

workers¹². Areas near to the ports and 50 kms distance from the coast are considered for this study, so that the traffic by the ships and the long cable laying can be avoided (Fig. 4).

Marine protected areas (MPAs) and marine sanctuary:

The sites which are protected by law cannot be considered as feasible sites for wind farm installation. Although usually considered to be areas designated for conservation of biodiversity, there are also other types of MPAs. They include fisheries reserves or —boxes’ where there may be seasonal closures or gear restrictions as part of a management regime for commercial fisheries, areas of archaeological interest, military exercise areas and safety zones around marine structures where access is restricted. Hence, such areas are not feasible for wind farm installation. Before considering the depth and wind parameters it is important to make sure whether the area is available for wind farm installation as per Indian laws. MPAs have to be considered for the same. The area influenced by tidal action up to 500 m from High Tide Line and Low tide Line has been declared as Coastal Regulation Zone (CRZ). Marine ecosystems were declared as the ecologically sensitive areas under the Environment Protection Act, 1986 banning their exploitation, followed by a CRZ Notification 1991 prohibiting development activities and disposal of wastes in the mangroves and coral reefs. The Coastal Regulation Act 1991 and 2011 was enacted by the Government of India to protect the Indian coasts from degradation. According to the CRZ Notification 2011, the coastal zone encompasses upto 12 nautical miles and all the land with which the sea has direct contact and also those portions of the land on which the sea has an influence indirectly through tidal action. Below is the table which lists the marine protected areas on

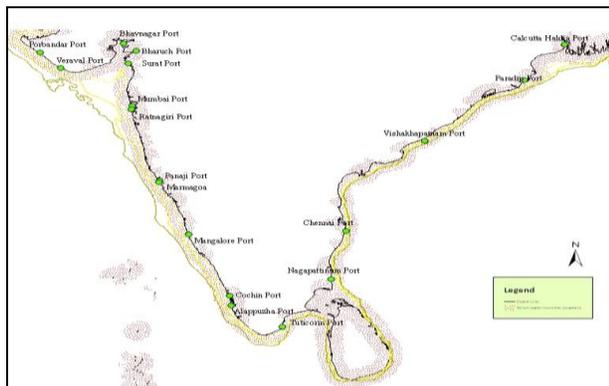


Fig. 4—Ports with 50 Kms coastline buffer

the Indian coast. Identification of the fishing areas or areas rich in fish species need to be identified prior to before planning an offshore wind farm so that minimum fish population is disturbed.

Results and Discussion

After considering bathymetry and wind, three feasible regions have been demarcated (Fig. 5). Two major regions emerge on the western side (Fig. 6, Fig. 7) and one on the eastern side. Bathymetry on the western part supports wind farm installation as there is a larger area that lies in lower depth as compared to the Eastern part. Wind velocity is quite good for wind power generation in the first two regions (Fig. 8). Table 2 lists the marine protected areas of which Sundarbans Tiger Reserve is an important one. Region 3 is falling on the eastern part of India which is at the proximity of the Sundarbans.



Fig. 5- Feasible regions along the Indian coast



Fig. 6—Feasible region 1 in west of coast of India

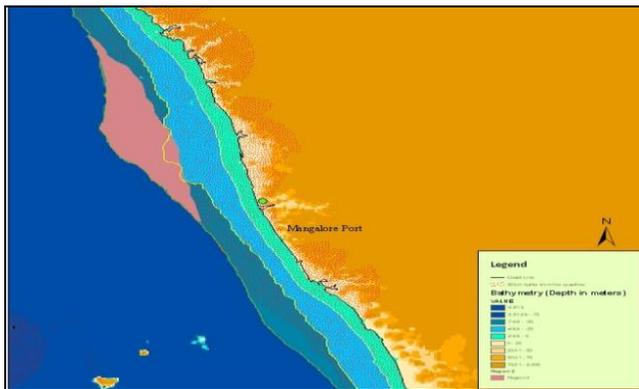


Fig. 7—Feasible region 2 in west of coast of India

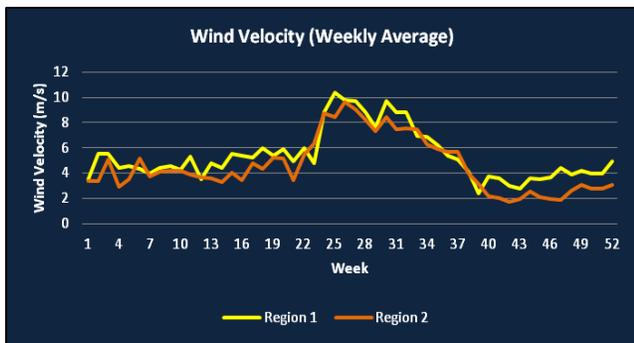


Fig. 8—Wind velocity comparison

Hence out of the three regions, region 3 is suggested as the least preferred region. Hence, Bay of Bengal is not feasible at present for wind farm installations. So, only the feasibility of wind farms on the western coast of India is further considered and recommended.

Table 2—Marine Protected Areas (Singh H.S 2003)

National Parks and Sanctuaries	Location	Area (ha)
Gulf of Kachchh Marine National Park	Jamnagar, Gujarat	16,289
Marine Sanctuary, Gulf of Kachchh	Jamnagar, Gujarat	29,503
Malvan Marine Sanctuary Sindhudurg	Maharashtra	2912
Bhitar Kanika NP	Cuttak, Orissa	14,500
Bhitar Kanika Sanctuary	Kendrapara, Orissa	67,200
Gahirmatha Marine Santuary	Kendrapara, Orissa	1,43,500
Chilka WLS	Puri, Orissa	1550
Gulf of Mannar Marine NP	Tamil Nadu	623
Pulicat Lake Sanctuary	Tiruvellore, Tamil Nadu	15,367
Point Calimere Santuary	Nagapattinam, Tamil Nadu	1726
Coringa Wildlife Sanctuary	East Godavary, Andhra Pradesh	23,570
Krishna Wildlife Sanctuary	Krishna/Guntur, Andhra	19,481

	Pradesh	
Pulicat Lake Bird Sanctuary	Nellore, Andhra Pradesh	50,000
Sundarbans National Park	West Bengal	1,33,010
Halliday Sanctuary	West Bengal	595
Lothian Island Sanctuary	West Bengal	3800
Sajnakhali Sanctuary	West Bengal	3624

Table 3—Classification of seasons (Source: Indian Meteorological Department)

Season	Month
Winter	January to February
Pre-Monsoon	March to May
Southwest monsoon (Summer)	June to September
Post Monsoon	October to December

There are certain thresholds that should be maintained for turbine installation and optimum power generation. Ideally, bathymetry should be in the range of 15 m to 75 m¹⁰. Wind Velocity is needed to be 5 m/s - 5.5 m/s for starting the power regulation and the velocity should not exceed 25 m/s¹³. Total number of weeks being 52 in a year; 52 wind velocity maps were prepared for detailed analysis. To make it simpler to understand and compare, seasonal wind velocity maps are presented in the next section for which the months have been divided into four seasons as shown in Table 3.

Region 1:

The region 1 is represented in Fig. 6. The area in this region is about 32,000 km² and the depth is in the range of 20 m to 75 m. The wind velocity ranges (minimum and maximum) between 3.3 m/s to 5.9 m/s during the winter season whereas during the pre-monsoon season it ranges between 3.6 m/s to 7.2 m/s. During summer monsoon wind velocity varies between 4.3 m/s to 10.2 m/s and during post monsoon season, it varies from 2.6 m/s to 5.6 m/s.

The region 2 is shown in Fig. 7. The region covers an area of about 6490 km² and the depth ranges between 40 m to 75 m. Wind analysis was repeated in the second region and it was found that in the winter season velocity ranges from 3.4 m/s to 4.3 m/s where as during pre-monsoon season it ranges from 3.8 m/s to 5.1 m/s. During the summer monsoon the wind speed varies from 4.3 m/s to 9.4 m/s and post monsoon season it varies from 1.9 m/s to 3.5 m/s. Minimum and maximum range of wind speed (m/s) in region 1 and 2 are represented in Table 4.

Table 4 clearly illustrates that in region 1 all the four seasons, the maximum wind speed exceeds the

threshold limit of 5-5.5 m/s. But in region 2, it exceeds only during pre-monsoon and summer monsoon periods.

Table 4—Wind speed (m/s) during all the seasons in region 1 and 2.

	Winter	Pre-monsoon	summer	Post-monsoon
Region 1	3.3-5.9	3.6-7.2	4.3-10.2	2.6-5.6
Region 2	3.4- 4.3	3.8-5.1	4.3-9.4	1.9-3.5

This confirms the wind potential feasible for power generation at these regions. Fig. 8 gives the comparison between region 1 and region 2 in terms of wind velocity. The average velocity in region 1 is higher as compared to region 2. In region 1, wind can be harnessed if the above mentioned criteria are followed for 26 weeks whereas in region 2, power can be generated for 20 weeks only. Also, in region 1 there are periods when cost optimum power generation can be carried out as the wind speed goes beyond 10 m/s.

Conclusion

Offshore wind energy is almost unexplored as far as India is concerned. There have been advances in the technology front and there is dire need on scientific methods. The feasible regions displayed above have very large areas and need to be studied in more detail. They exhibit the necessary wind availability for different seasons which should be commercially exploitable. Region 1 is the best for all the four seasons and the region 2 is good during pre-monsoon and summer monsoon periods. Further studies with more parameters can bring out smaller and precise areas within these larger regions. Wind potential in this region is not as high as the pacific waters and hence there should be more research to be carried out to enhance the technology so that the energy can be harnessed even at lower wind velocity. The Electricity Act 2003 defines policy formulation and optimal use of all resources including renewable sources of energy. It is suggested to form a dedicated policy and frame work for the promotion of offshore wind energy so that the presence and potential of off

shore wind energy can be tapped to the fullest.

Acknowledgement

Authors acknowledge Director, NIO for the support and the interest shown in this study. QuickSCAT data are produced by Remote Sensing Systems and sponsored by the NASA Ocean Vector Winds Science Team. The NIO contribution No is 5623.

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