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PRE-FEASIBILITY STUDY

FOR OFFSHORE WIND FARM DEVELOPMENT IN GUJARAT

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FOREWORD

On behalf of the FOWIND consortium, we are pleased to present the Pre-feasibility Report for the State of Gujarat, which is an important outcome of the project's first year. The four year project aims to put together a roadmap for developing a sustainable and commercially viable offshore wind industry in India.

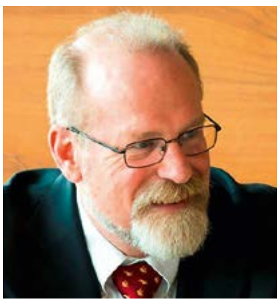
The report outlines a number of credible technical solutions for offshore wind development in eight potential zones identified through constraint modelling using existing public domain data. While it is understood that the success of India's entry into the offshore wind market will depend on full-scale feasibility assessments, this report offers a starting point to that process which is also included under the FOWIND project's scope.

India, already a key global player in the field of onshore wind, is under increasing pressure to meet its energy deficit – a growing concern due to a booming population – using indigenous and low carbon sources. While costs of offshore wind projects are still high, there are clear indications that they can be brought down substantially through experience and economies of scale. The rewards in India have the potential to be great: a strong, steady resource that can play a major role in supplying clean energy to the major load centers in coastal cities and industrial areas such as Gujarat.

This report covers high level, preliminary studies on project siting, wind farm design and installation strategies. Project costs are suggested using international experience and environmental considerations are covered. Finally, initial LiDAR device locations are suggested for crucial onsite offshore wind measurements, needed to improve upon and validate the existing studies which this report relies on.

Growing renewable energy incentives from the Indian Government makes this an exciting time to explore the future of offshore wind in India. We hope you find this pre-feasibility study for Offshore Wind Farm Development in Gujarat (and a similar report for Tamil Nadu) a useful document.

Steve Sawyer
Secretary General
GWEC



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ABOUT FOWIND

The consortium led by the Global Wind Energy Council (GWEC) is implementing the Facilitating Offshore Wind in India (FOWIND) project. 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).

The project seeks to establish structural collaboration and knowledge sharing between the EU and India on offshore wind technology, policy and regulation and serve as a platform for promoting offshore wind research and development activities. The project focuses on the states of Gujarat and Tamil Nadu for identification of potential zones for development through preliminary resource and feasibility assessments for future offshore wind developments, as well as through techno-commercial analysis and preliminary resource assessment. The project consists of a total of seven work packages.

This report has been developed as part of Work Package 1 on review of existing studies, gap and pre-feasibility analysis of offshore zones in Gujarat and Tamil Nadu. Under this package WISE and C-STEP would engage with multiple state agencies of Gujarat and Tamil Nadu respectively to collect the required data and information. DNV GL will conduct a desktop study to identify any key technical constraints based on data available in the public domain. DNV GL will further consider the impacts of shipping in and around local port infrastructure as well as highlighting any environmental risk factors.

The above datasets will be used in conjunction with DNV GL's in-house Geographic Information System (GIS) and a high level scoring will be undertaken to identify areas of interest. To inform the above assessment, DNV GL will develop a wind map covering the full extent of the Gujarat and Tamil Nadu offshore zone to a distance of 12 nautical miles from shore. DNV GL will use a meso-scale modelling package, such as Wind Resource Forecasting (WRF), to predict the wind regime over the region of interest. Meso-scale modelling uses climate data based on global climate reanalysis models to initiate wide-area indicative wind speed modelling.

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The impression of the Indian state of Gujarat used on the cover page is for indicative purposes only.

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This report is available for download from www.fowind.in and the websites of respective project partners.

EXECUTIVE SUMMARY

This desktop study offers a preliminary overview of the potential for offshore wind development in the Indian state of Gujarat. Completed under Work Package 1 of the FOWIND (Facilitating Offshore Wind in India) project; technical, financial, social and environmental parameters were considered to identify eight potential zones for further study. Further high level technical, financial and social-environmental studies were conducted focusing on key offshore wind project components. A parallel study has been completed for the state of Tamil Nadu.

Globally, the offshore wind power industry is maturing and increasingly coastal countries are utilising this new, indigenous and carbon neutral source of energy. For a relatively young industry relying on considerable investment, research and development activity is spurring progress in leaps and bounds, leading to ever better economic prospects and improving the energy security of coastal states.

India, with a vast coastline of over 7,600 km is beginning to explore offshore wind energy as a ‘strategic energy source’ to enable long term energy security.

This pre-feasibility study relies on existing public domain data, documented international experience and proven characteristics of offshore wind energy technology to suggest plausible options for the Indian market.

Key findings formulated during the course of this pre-feasibility study are summarised as follows:

- **Wind Resource** – to date no publically available on-site wind measurements have been recorded within the Gujarat offshore zone;
- **Zone Selection** – eight zones have been identified with mean wind speeds in the range of 6.8 to 7.0 m/s (at 120 m AGL) and water depths in the range of 15 to 43 m below LAT;
- **Turbine Selection –** predicted extreme typhoon wind conditions meant Class I or S wind turbines were taken forward for further investigation;
- **Energy Yield –** for the eight zones and calculated wind speeds, Project Net Capacity Factors were estimated in the range of 18.5 % and 29.7 % (depending on the particular zone, MW capacity of the farm and the turbine MW capacity);
- **Foundations –** monopile, jacket and tripod foundations would be likely choices to take forward for the next stage of investigation;
- **Electrical –** there is a healthy grid infrastructure present in the state of Gujarat with at least two high voltage substations;
- **Installation –** the preliminary screening study has identified seven ports with some potential. Vessel availability in the region is high but not optimised for offshore wind. The consortium recommend that site-specific transportation and installation planning is conducted during the early project development stages;
- **Operations & Maintenance –** it is assumed that all the first offshore wind projects in India will use an O&M strategy based on work boat access;
- **Cost of Energy –** wind resource is the most significant factor affecting offshore wind Cost of Energy (COE);
- **Risks –** the greatest risks highlighted during the pre-feasibility study are associated with the limited data available for the assessment. Where data were available, it is subject to high uncertainty. Specifically data relating to the following key areas: offshore wind resource, metocean climate, geotechnical conditions and grid connection;
- **Environmental –** Gujarat is home to sensitive marine ecosystems, including; coral reefs, mangroves, various marine mammals/organisms and areas of archaeological significance.

In summary it is of paramount importance that the current high uncertainty with regards to zone level wind resource estimates, energy predictions, ground conditions, metocean data and cost of energy are reduced and mitigated before the true level of offshore wind feasibility can be identified for Gujarat. The Consortium plan to achieve this through delivery of the ongoing FOWIND work packages; that will include:

- On-site LiDAR wind measurement campaign;
- Identification of further constraint data, with regards to ground conditions and metocean data;
- Full Site Specific Feasibility Study;
- Logistics and Infrastructure Assessment;
- Grid Connection and Transmission Assessment;
- Stakeholder Engagement Workshops.

1 INTRODUCTION

The FOWIND consortium's, Gujarat Pre-Feasibility Study Report, is a key deliverable from the project's first year of work and is the consecutive step following the FOWIND Inception Report published in 2014 [1].

The objective of this report is to support companies and government institutions in developing a better understanding of typical offshore wind project considerations. This study will now form the starting point for future offshore wind feasibility investigations. A parallel study has been conducted for the State of Tamil Nadu.

The study is based on a comprehensive review of existing literature available in the public domain, and on applied experience and knowledge gained in over 10 years of commercial European offshore wind projects.

To begin with, known constraint parameters were modelled to identify eight potential development zones in Gujarat. A number of key constraints have been considered, combining both technological barriers and spatial conflicts. As one of the key parameters a mesoscale wind resource map was modelled encompassing Gujarat's coastal waters within the Indian Exclusive Economic Zone (EEZ).

Zone identification is followed by a preliminary wind farm design for each zone. Two indicative project capacities of 150 MW and 504 MW have been considered since these are broadly representative of typical European commercial offshore wind developments. Similarly, two wind turbine generator (WTG) sizes of 4 MW and 6 MW have been considered in the modelling. These capacities are representative of established (4 MW) and current (6 MW) offshore wind turbine designs.

Based on these wind farm capacities and turbine sizes, a high level Annual Energy Production (AEP) assessment has been carried out for all eight zones and indicative Capacity Utilisation Factors (CUF) have been estimated.

Technical considerations have been examined at high level for the identified zones. These comprise a foundation screening study, a wind farm electrical concept study, installation considerations (ports, vessels and installation methodologies) and operation and maintenance considerations.

Based on the estimated wind resource potential, technical considerations and preliminary project costing, Levelised Cost of Energy (LCOE) heat maps were developed for the eight identified zones. A preliminary risk assessment was conducted to identify areas which require more detailed assessments.

Beside high level technical considerations; social, environmental and legal aspects have been touched upon in this study. Associated costs are to be considered as strongly dependent on the individual project characteristics and therefore have not been reflected during LCOE assessment.

Detailed descriptions for the applied methodology of the individual studies are provided with in each section of the report.

Following this base line study the FOWIND consortium will conduct further detailed assessments on the most suitable zones over the following years of the project; and in doing so help further reduce the level of uncertainty associated with the pre-feasibility results.

2 SUMMARY OF REVIEW OF EXISTING STUDIES

The FOWIND Inception report [2] was completed in 2014. The key focus of this was to assess the offshore wind conditions and infrastructure in India within the States of Gujarat and Tamil Nadu, based on the review of existing literature. Several national and international institutions have studied India's offshore wind resources.

These publically available studies [3] [4] [5] [6] [7] [8] [9] [10] [11] [12], which are summarised in the Inception Report, were generally based on modelled wind data using a combination of onshore weather stations at low heights (10 m to 50 m above ground) and satellite data. There is inherently a high level of uncertainty associated with this information. Further assessment, which falls within the scope of the FOWIND project, is required to validate offshore wind resources. Offshore wind measurement, using LiDAR (Light Detection and Ranging) data acquisition, will commence in the coming year, under Work Package 4. LiDAR systems are a remote sensing technology used to measure wind speed on and offshore.

Some studies have attempted to identify potential areas for development of offshore wind and its feasibility for installation. For example, one author proposes a number of zones within the north eastern Arabian Sea as suitable for development. Again, the limitations and inconsistencies with these studies appear to relate to a lack of validated data sets. In some publications, spatial constraints and met-ocean conditions were not fully considered while estimating the offshore wind potential, but in general the conclusions were in agreement that the best offshore wind power densities within Gujarat, were located along the Saurashtra coast, in the Gulf of Khambhat and in the Gulf of Kutch [5] [6] [7].

India's existing onshore wind farms frequently risk curtailment due to weak transmission infrastructure. Most of the existing and proposed substations along the coastline are rated at 220 kV or 400 kV (capacity) which will need upgrading to accommodate offshore wind power. Furthermore, strengthening of the western and northern regions' transmission corridor originating from Gujarat is vital to improve grid connectivity and balance reserves at a national scale. Generally speaking, grid infrastructure is lagging behind renewable energy development, (which requires a transmission system capable of absorbing higher levels of variable generation), due to comparatively higher gestation periods. Political support that enables long term integrated energy planning is a key component particularly when developing renewables.

No substantial port studies have been undertaken to date. To assess suitability of existing infrastructure, this is included within the FOWIND project's scope. It is noted that the Gujarat Maritime Board (GMB) is responsible for approximately 41 ports in the State and promotes the development of greenfield ports under private management (Build Own Operate Transfer – BOOT). Out of 11 greenfield sites identified by the GMB, 4 are operational and facilitate direct berthing in all weather conditions. Distance from an offshore wind development site to the nearest suitable port (with adequate storage, cranes, water depth and channel widths to accommodate all required construction vessels) is a crucial factor in determining a project's economic feasibility due to the high leasing cost of specialist vessels. Equally, export cabling costs are proportionate to the installation's distance from shore.

In summary, based on the limited resource assessments carried out along the Indian coast, there appear to be areas within Gujarat that offer considerable potential for offshore wind development.

There are regions in the Gulf of Khambhat, Gulf of Kutch and Saurashtra coastal zones with identified wind speeds in the range of 6-12 m/s at 50-120 m hub heights [4].

To reduce the uncertainties involved with the existing literature, wind resources will be validated and other site-specific constraints will be assessed under the scope of the FOWIND project to provide the next step for offshore wind development in India.

3 OFFSHORE WIND RESOURCE MODELLING

3.1 Introduction

The objective of this section is to validate the existing and available wind resource findings.

The wind climate has a significant influence on the economic viability of offshore wind development for the Gujarat region. A description of the long-term wind climate at a potential wind project is best determined using wind data recorded at the site. For Gujarat, no long term wind data are available and the wind resource modelling studies require validation (see Section 2). Therefore the analysis presented here is not validated and subject to high levels of uncertainty.

This section covers the following:

- methodology used by DNV GL's mesoscale wind modelling to predict the wind regime over the area of interest (see Section 3.2);
- discussion regarding the model outputs;
- wind speed confirmation and uncertainties.

3.2 Wind flow modelling

The spatial variation in wind speed at heights of 80 m, 100 m and 120 m (typical hub heights for offshore wind turbines) above sea level has been predicted by the consortium partners for the areas considered using the Mesoscale Compressible Community ("MC2") computational model as developed by Environment Canada. For this application, MC2 has been run at approximately 5 - 6 km resolution[1] in EOLE mode in which a finite number of climate states are defined according to a global database of geostrophic weather statistics based on public domain reanalysis hindcast data. The National Centre for Environmental Prediction (NCEP) / National Centre for Atmospheric Research (NCAR) reanalysis dataset has been used for this purpose.

In this mode of operation, a number of simplifying assumptions are made relating to atmospheric stratification to allow for a faster convergence for the sake of computational efficiency. In addition, certain thermally driven atmospheric phenomena such as katabatic and anabatic flows are neglected in the modelling, again to allow computational efficiency gains. These simplifications are not considered to significantly alter the wind energy potential predicted by the model. Each climate state is simulated individually until convergence has been reached.

Following the simulations for each of the standard climate states, the results are weighted by frequency of occurrence [13]. The results from the mesoscale modelling have then been used to initiate the MS-Micro linear wind flow model. This model has then been used to predict the wind regime, with a grid spacing of approximately 500 m, across the region of interest.

The geophysical model, which is comprised of surface roughness and elevation data, is a crucial input to the wind flow modelling process, and has been based on a number of databases. Typically Anemoscope utilises the GenGEO database [13] for this purpose. However, due to a number of inconsistencies noted in the GenGEO database, alternative sources were sought.

[1] The 5 – 6 km resolution - a small discrepancy between the two models of Gujarat and Tamil Nadu due to the size restrictions of modelled domains in Anemoscope. The final microscale output has been maintained between the models at the same resolution. However, another variable is that Anemoscope works only in a polar stereographic projection system. When converted back to a regular grid varies slightly across the domain with latitude.

The mesoscale surface roughness has been based on land cover information obtained from the ISCGM database [14], which provides worldwide data at a resolution of 30 arc-seconds (approximately 1 km) and is understood to be more accurate and up to date than the GenGEO database. To accommodate the increased resolution of the modelling domain, the surface roughness used for the microscale modelling procedure was digitised by the FOWIND consortium based upon an assessment of land cover shown by aerial and satellite imagery provided by Google Earth. The land cover is relevant largely for wind directions where the wind first passes over land then to sea, but also has an impact on the land/sea interface at the coastline. How quickly and to what extent the ocean wind flows are affected as this passes over the coastline to land is a function of the surface roughness and topographic elevation. This can have impact further upstream, and is therefore still a significant effect to try to capture. The FOWIND consortium partners have also included a digitisation of the coastline in this process, to more accurately define this important feature in the model.

The elevation data used for the model comes from either the SRTM30 or SRTM3 [15] databases. These two databases provide worldwide elevation data at a horizontal resolution of 30 and 3 arc-seconds respectively (approximately 1 km and 100 m). The lower resolution SRTM30 data set has been used as an input to the mesoscale model, while higher resolution SRTM3 data has been employed during the microscale modelling.

These sources of terrain data, along with the NCEP/NCAR Reanalysis dataset [16], provide the models with the information needed to simulate the wind flow over the designated area.

3.3 Model outputs

The results obtained from the MC2 mesoscale model include detailed information on the wind regime at each point on the grid established over the modelled area, at a resolution of approximately 5 - 6 km.

The results obtained from the MS-Micro microscale model include mean wind speed at each point in the 500 m resolution grid established over the modelled area.

Mesoscale and microscale wind flow modelling was carried out to determine the wind speed variation over the study area.

The wind speed results have been compared to an alternative set of mesoscale modelling results, and will be reviewed after completion of the monitoring outlined in Work Package 4 (LiDAR Assessment). The results of this work for Gujarat, as part of the pre-feasibility study, are shown within Appendix 1 as wind speed maps for 80 m, 100 m and 120 m above sea level.

3.4 Wind speed confirmation

If reliable long-term reference wind speed measurements are available within the modelled area, they can be used to validate or calibrate the wind speed maps obtained from Anemoscope and reduce the uncertainty associated with the results.

The FOWIND consortium has not been provided with any offshore measured wind speed data, nor is it aware of any sources of long-term offshore reference data in the region. Therefore additional confidence in the predicted variation of wind speeds across the site was obtained through comparison with alternative mesoscale modelling results sourced from DNV GL's Virtual Meteorological Data (VMD) service at specific locations across the study area.

The VMD service is a mesoscale-model-based downscaling system that provides high resolution long-term reference time series for any location in the world. At the core of VMD is the Weather Research and Forecasting (WRF) model, developed and maintained by a consortium of more than 150 international agencies, laboratories and universities. VMD is driven by a number of high resolution inputs, such as Modern-Era Retrospective analysis for Research and Applications (MERRA) reanalysis data [17], global 25 km resolution 3 hourly and daily analyses of soil temperature and moisture, sea surface temperature, sea ice and snow depth. A sophisticated land surface model predicts surface fluxes of heat and moisture in the atmosphere, reflected shortwave radiation, and longwave radiation emitted to the atmosphere.

MERRA is a NASA reanalysis product which couples numerical modelling with large quantities of empirical data such as surface measurements and earth observation satellite data to generate a long term continuous datasets. MERRA data is available on an hourly basis over a grid spanning most of the globe at a resolution of 1/2 ° in latitude and 2/3 ° in longitude and at a height of 50 m above ground level.

Mean wind speeds across the study area were predicted from VMD simulations at heights of 80 m, 100 m and 120 m above sea level. The mesoscale wind speed results from Anemoscope were then compared to the mesoscale results obtained from the VMD service at the study heights. Adjustments were made to the Anemoscope microscope results in order to bring them into agreement with the VMD results in areas where it was deemed that the VMD results were more accurately reflecting the wind regime.

The absence of offshore wind speed measurements and the nature of the modelling results should be considered when interpreting the wind speed map produced. There is significant uncertainty associated with the process used here to confirm the modelling results, and therefore also with these preliminary wind speed results.

To help reduce some of the uncertainties associated with the current studies, the FOWIND project intends to deploy one LiDAR device at a fixed platform in Gujarat. The FOWIND consortium will update the results presented here upon review and validation of the data obtained from the measurement campaign.

3.5 Consideration of uncertainty

It is not considered appropriate to formally quantify the uncertainty associated with the results presented here; however some of the sources of uncertainty are discussed below. Due to the uncertainty associated with the modelling process, the FOWIND consortium recommends that the results presented are used for pre-feasibility purposes only.

There is uncertainty inherent in the results of the mesoscale simulation due to:

- Assumptions and simplifications inherent in the modelling process;
- The limited fidelity of the land cover database; and
- Re-gridding of the geophysical model at a grid spacing of approximately 5 - 6 km.

The microscale modelling uses an increased grid resolution with spacing of approximately 500 m. This enables the terrain and hence the wind flow to be modelled at a higher resolution. In order to best interpret the microscale modelling results the following points must be noted:

- The mesoscale modelling output is used as input data and consequently the uncertainty in the mesoscale modelling is inherent in the microscale wind speed predictions;
- The wind speed confirmation has been based upon alternative mesoscale modelling results, without any reliable measurements in the region to support the findings; and
- The modelled wind speeds have not been validated against measurements.

4 SELECTION OF POTENTIAL WIND FARM ZONES

4.1 Introduction

The objective of this section is to identify potential offshore wind farm development zones off the coast of Gujarat by applying hard and soft constraints.

The FOWIND consortium partners have defined a study area of coast surrounding the state of Gujarat. The initial area in Figure 1 is based on the basic constraints defined below.

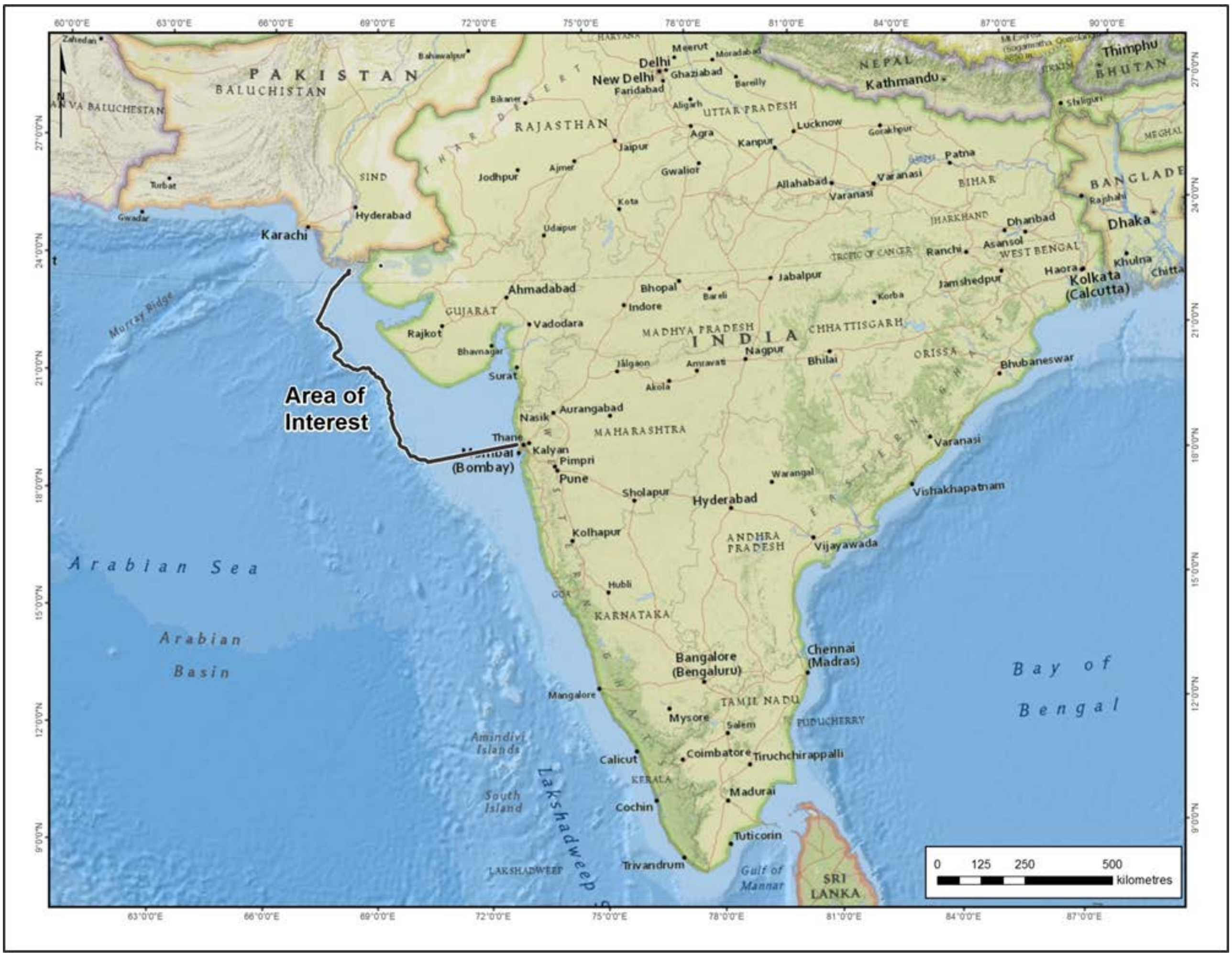


Figure 1: Area of Interest.

The FOWIND consortium has made use of publically available data to produce development constraints for offshore projects near the State of Gujarat. At this stage these constraints were formed to be conservative to allow a large area to be modelled and considered.

The proposed offshore wind farm must be located within the following basic constraints:

1. Contained within the Indian Exclusive Economic Zone (EEZ);

2. Located within a maximum water depth of 500 m (based upon current estimate of the maximum foreseeable depth for floating wind turbines);

3. Contained within an approximation of the theoretical Gujarat state maritime boundaries which are assumed to extend perpendicular to the coastline from points approximately 100 km along the coastline of the adjoining states;

Figure 32 and Figure 33 in Appendix 1 shows the boundaries associated with the first two constraints presented above, whilst Figure 2 shows the combination of all three development restrictions where the remaining white area is considered to be the area of interest for this study.

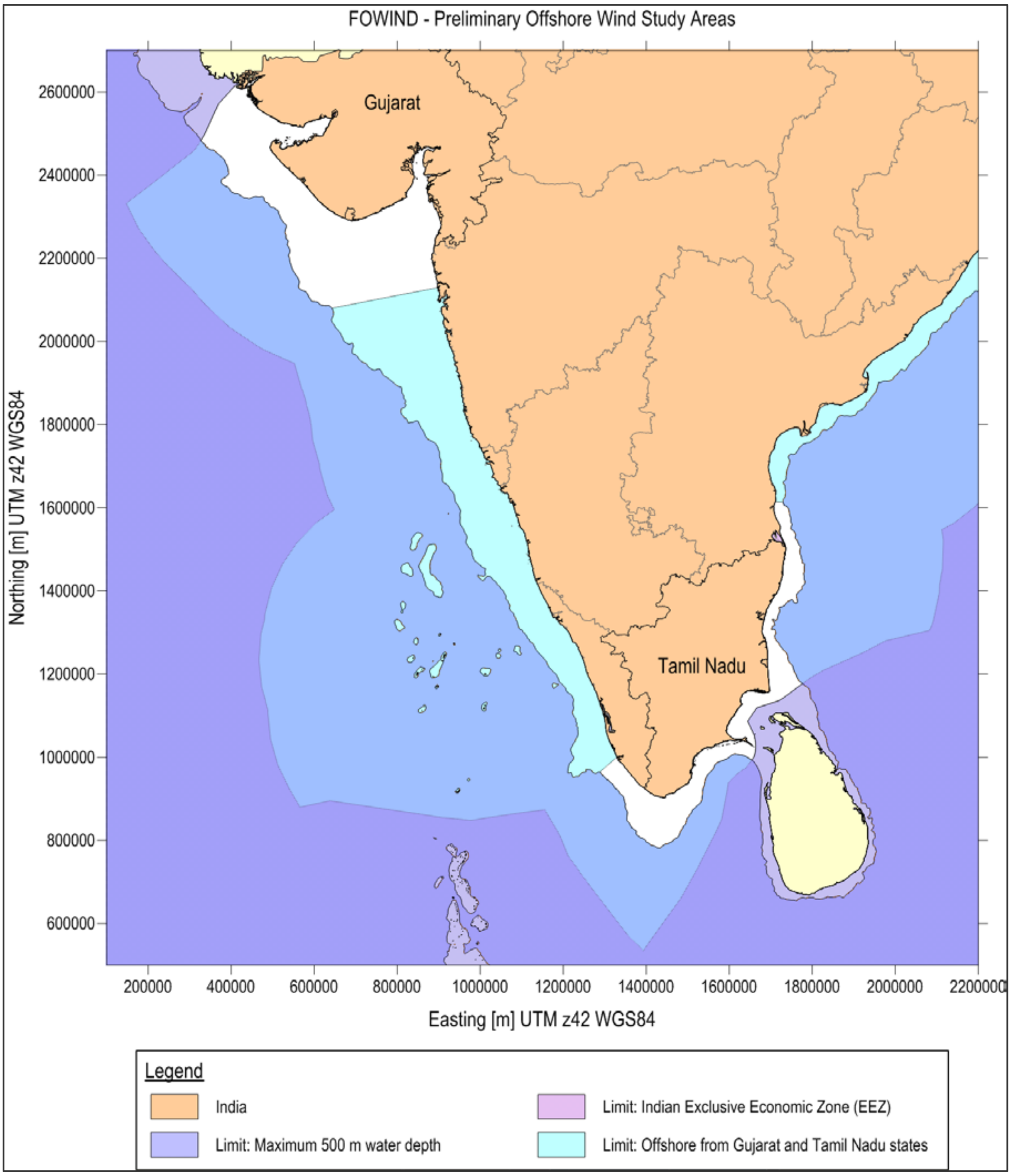


Figure 2: Preliminary limit for offshore wind development – primary constraints combined.

Source: [18]

4.2 Methodology

The potential zones, considered most suitable for offshore wind energy development, were identified by pragmatically ranking their compliance with a set of defined technical and environmental parameters.

The methodological approach is summarised in the following five main steps:

1. Mapping and identification of spatial constraints (e.g. environmental features, built features, wind resource, transmission lines, etc.);
2. Removal of areas of constraint, defined as those which directly impact both the technical, commercial and social-environmental feasibility of an offshore wind development;
3. Pragmatic weighting of the remaining area, outside the defined 'hard' constraints, to identify suitable sites for wind farm development, taking into consideration the factors which impact the technical and commercial feasibility of wind farm development;
4. Identification of the most promising sites (iterative process); and
5. Ranking, analysis and description of identified sites.

Note definition:

Hard Constraint: those which directly impact on both the technical and commercial feasibility of an offshore wind in the study domain.

Soft Constraint: those which impact, to a lesser extent than hard constraints, the technical and commercial feasibility of offshore wind development.

4.3 Identification of exclusion zones constraint parameters

In order to allow for an informed selection of zones that should be investigated in greater detail for Gujarat, a number of hard constraints and a limited number of soft constraints (e.g. visual impact) have been considered. These constraints consist of a combination of technological barriers and spatial conflicts which are considered to restrict the deployment of offshore wind turbines. The constraints detailed in Table 1 and Table 2 have been considered.

Table 1: Environmental and Biophysical Constraints.

Features	Findings within the area of interest	Potential Setback or Consultation Zone	Rationale	Source of the Data
Offshore Wind Resource	Few zones are located near the coast	< 6 m/s	Best practices for economic sustainability	DNV GL
Water depth	Few zones of low water depth are located along the coast. *Inter-tidal risks not considered here.*	> - 5 m and < - 500 m	Best practices for economic sustainability and technology	General Bathymetric Chart of the Oceans (GEBCO)
Coral Reef	Few coral reef are located within the Gulf of Kutch	10 km	Best practices to minimise impacts	Global distribution of Coral Reefs (2010)
Mangrove	Several mangroves are located within the Gulf of Kutch	10 km	Best practices to minimise impacts	Global distribution of Mangroves USGS (2011), World Atlas of Mangroves (2010)
Sandbar of shallow water	Few sandbar areas are located along the coast	Avoided	Best practices to minimise impacts	General Bathymetric Chart of the Oceans (GEBCO)
Seismic Risk	Indian earthquake Zone 5 risk zone (highest seismic risk) identified northwest of the area of interest	Avoid zone of highest seismic risk (Zone 5)	Best practices to minimise impacts	India Meteorological Department (Ministry of Earth Sciences) Mercalli Intensity Scale of India
Sediment Thickness	Sediment thickness is greatest closest to the coast	Within the EEZ	Best practices to minimise impacts	National Oceanic and Atmospheric Administration (NOAA)
Cyclone	Highest cyclone density registered in the northwest coast	Within the EEZ	Best practices to minimise impacts	Cyclone path (1946 to 2007) provided by CSTEP

Table 2: Human Environmental Constraints.

Features	Findings within the area of interest	Potential Setback or Consultation Zone	Rationale	Source of the Data
Shipping Lanes	Few shipping lanes are located within the area of interest	0.5 nautical miles from the shipping lane boundary	Best practices for navigation safety	Admiralty Chart of India
Visual Impact	Along the coastline	8 km	Best practices to minimise visual impacts	OpenStreetMap (coastline)
Oil and Gas Field	Tapti, Bombay High, Mukta – Panna and Bassein oil and gas fields are located within the area of interest	Avoided	Best practices to minimise impacts	Admiralty Chart of India
Oil and Gas Platform	Few platforms are located within the gulf of Kutch and south of the Gujarat	0.5 nautical miles	UK Maritime Guidance Note MGN-371	Admiralty Chart of India
Oil and Gas Pipeline	Few pipelines are located southeast of Gujarat	0.5 nautical miles	UK Maritime Guidance Note MGN-371	Admiralty Chart of India
Submarine Communication Cable	Few submarine communication cable are located south of the area of interest	0.5 nautical miles	UK Maritime Guidance Note MGN-371	Admiralty Chart of India

4.4 Weighting of spatial influences

In order to aid the selection of zones a scoring mechanism has been derived which takes into account the key technical and consenting factors considered. A summary of the scoring results are provided in Table 3.

Table 3: Ranking Criteria.

Factor	Criteria / Description	Relative Weighting [%]	Ranking Score	
			Class	Score
Wind Resource	F1. Wind speeds equal or greater than 6.0 m/s and less than 8.5 m/s	40	6.0 – 6.5 m/s	0 - 3 (Worst)
			6.5 - 7.0 m/s	3 – 6
			7.0 - 7.5 m/s	6 – 8
			7.5 - 8.0 m/s	8 – 9
			8.0 – 8.5 m/s	9 - 10 (Best)
Development Complexity	F2. Water Depth between 5 m to 200 m	30	200 - 60 m	0 – 5.6
			60 - 30 m	5.6 - 7.1
			30 - 5 m	7.1 - 10
	F3. Proximity with construction ports up to 230 km *(Ports identified have not been considered for their capabilities for offshore wind construction, this should be part of a further detailed study)*	10	230 – 184 km	0 - 2
			184 – 138 km	2 - 4
			138 - 92 km	4 - 6
			92 - 46 km	6 - 8
			46 - 0 km	8 - 10
	F4. Distance to existing transmission grid *(inland and subsea transmission grid considerations)*	12.5	230 – 184 km	0 - 2
			184 – 138 km	2 - 4
			138 - 92 km	4 - 6
			92 - 46 km	6 - 8
			46 - 0 km	8 - 10
Environmental	F5a. Proximity to pipelines	2.5	Between 0.5 – 2 nautical	0 - 10

Factor	Criteria / Description	Relative Weighting [%]	Ranking Score	
			Class	Score
	F5b. Proximity to oil and gas platforms			
	F5c. Proximity to shipping lanes			
Social and Environmental	F6. Visual impact (distance to coastline)	2.5	Between 8 – 50 km	0 – 10
	F7. Seismic Risk between intensity zones < 5 to 1 (Intensity zone 5 highest risk zone avoided)	1	Intensity zones <5 - 4	0 - 2
			Intensity zones <4 – 3	2 – 4
			Intensity zones <3 – 2	4 – 8
			Intensity zones <2 – 1	8- 10
	F8. Cyclone Risk (Only "cyclone risk" areas have been identified. Extreme wind speed influences should be investigated as part of a further detailed study)	1	Highest to lowest density of cyclone	0 - 10
	F9. Sediment Thickness	0.5	Lowest to highest sediment thickness	0 – 10

Nine major constraints have been identified which are likely to have a significant impact on the feasibility of deploying a commercial scale offshore wind farm in the study domain. To quantify the impact of these constraints, a score between 0 (least feasible) and 10 (most feasible) was attributed. In addition a relative weighting has been assigned to each constraint which represents the relative importance it has on the overall feasibility of project development.

4.5 Preliminary potential zones for development

Having assigned scores and relative weights for each criteria, overall scores have been developed across the study domain. This process has resulted in a scoring map (referred henceforth as a "heat map") across areas of the study domain, with the exclusion of areas outside the identified constraints. The resulting heat maps for the study domain are presented in Appendix 2.

Based on the assessment conducted by the FOWIND consortium, eight preliminary potential zones have been identified for the development of commercial scale offshore wind farms. Due to the level of uncertainty associated with the preliminary constraints data and the lack of on-site wind measurements to validate the modelling process, it is recommended that the results presented in this study are used solely for pre-feasibility purposes only.

Figure 3 shows the identified eight potential zones. Based on the assessment conducted, features of these eight zones are described in Table 4.

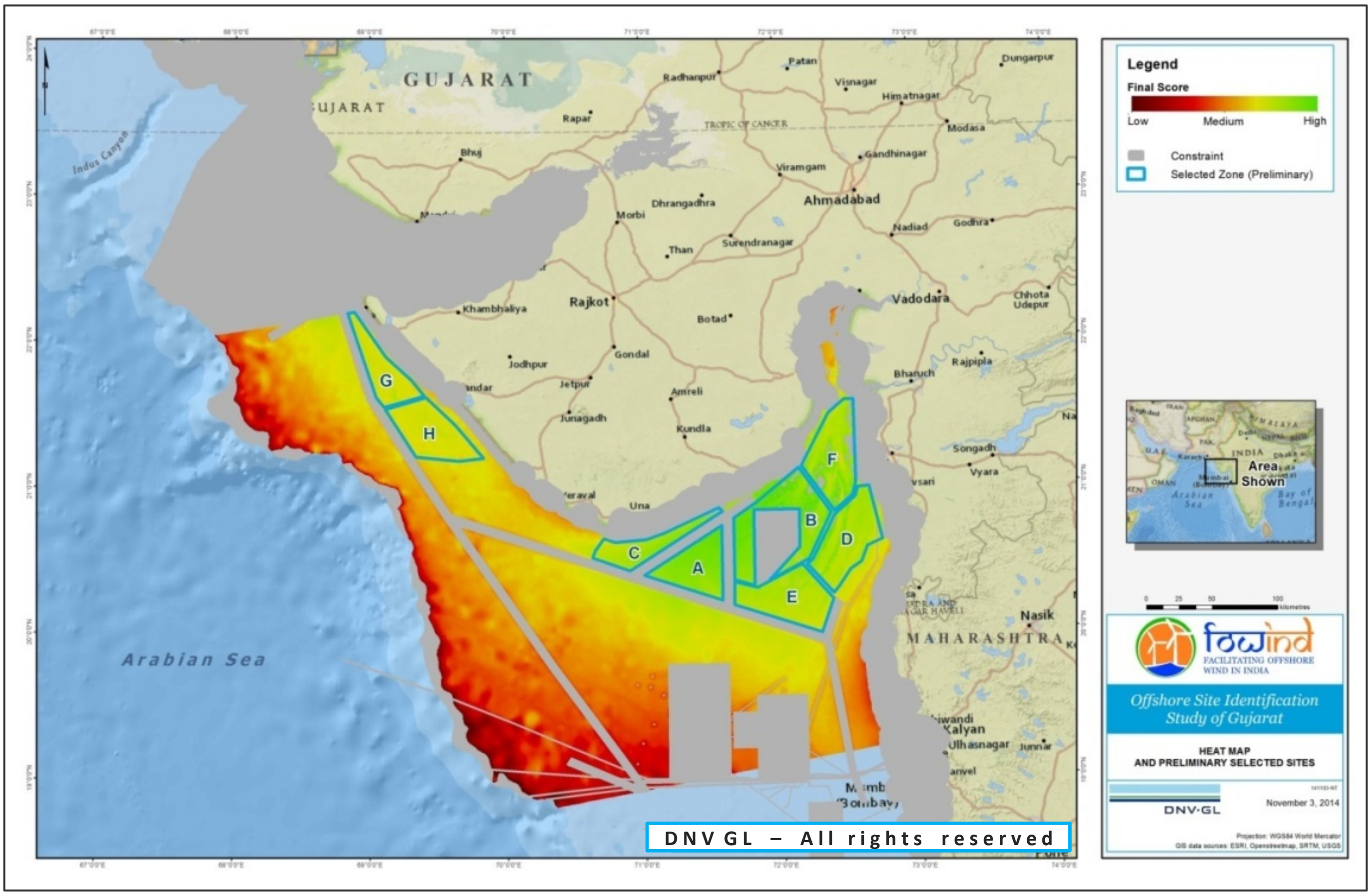


Figure 3: Heat Map Showing Preliminary Site Selection.

Table 4: Potential Zones for Development of Offshore Wind Power Project.

Zone ID (highest to lowest score)	Indicative Mean WS at 120 m AGL (m/s)	Indicative Mean Percentage WS change between 100 m and 120 m AGL[2]	Indicative Mean Percentage WS change between 80 m and 100 m AGL[3]	Mean depth (mLAT)	Minimum distance to existing substation (km)	Area (km^2)	Notes
A	7.0	0.8%	1.8%	-24	23	1,921	- Safety: shipping lane in vicinity. - Closest ports: Jafrabad, Pipapav, Navabandar, Diu.
B	7.0	0.9%	2.1%	-17	26	2,924	- Shallow water: a few sand bars are located within the zone. Bathymetry at higher resolution is recommended (i.e. Tcarta). - Located within Oil & Gas leased area: potential conflict use between Oil and Gas development and offshore wind development. This zone is close to Tapti oil and gas field, one submarine pipeline and 4 oil and gas platforms. - High resolution nautical charts are recommended. The zone possibly intersects a shipping lane. - Closest ports: Pipavav, Mahuva.
C	6.9	1.4%	3.1%	-28	9	1,414	- Safety: shipping lane in vicinity. - Closest ports: Jafrabad, Pipavav, Navabandar, Diu, Chhara.
D	6.8	1.0%	2.2%	-22	15	2,547	- Shallow water: a few sand bars are located within the zone. - Bathymetry at higher resolution is recommended (i.e. Tcarta). - One submarine pipeline intersects the zone D. - High resolution nautical charts are recommended. The zone possibly intersects a shipping lane. - Closest ports: Vansi Borsi, Hazira, Nargol.
E	6.9	0.8%	1.7%	-26	45	2,503	- Safety: shipping lane in vicinity. - Two oil and gas platforms are located within zone E and one submarine pipeline is located northeast of the zone. - Closest port: Nargol.

[2] Only wind speed at 120 m AGL have been used in the zone identification. Wind speeds at 100 m are stated for reference ONLY. Stated wind speeds are indicative and require validation.
[3] Only wind speed at 120 m AGL have been used in the zone identification. Wind speeds at 80 m are stated for reference ONLY. Stated wind speeds are indicative and require validation.

F	6.8	1.3%	2.8%	-15	9	2,519	- Shallow water: a few sand bars are located within the zone. - Bathymetry at higher resolution is recommended (i.e. Tcarta). - High resolution nautical charts are recommended. The zone possibly intersects a shipping lane and two oil and gas platforms are located within the zone. - Closest ports : Hazira, Alang, Mithivirdi, Dahej. - Noted for high-tidal flows, see Section 6.1.6.3
G	6.8	1.2%	2.6%	-42	13	1,624	- Safety: shipping lane in vicinity. - Closest ports: Dwarka, Bhogat and Porbandar.
H	6.8	1.2%	2.6%	-43	16	2,254	- Safety: shipping lane in vicinity. - Closest port: Porbandar.

[2] Only wind speed at 120 m AGL have been used in the zone identification. Wind speeds at 100 m are stated for reference ONLY. Stated wind speeds are indicative and require validation.

[3] Only wind speed at 120 m AGL have been used in the zone identification. Wind speeds at 80 m are stated for reference ONLY. Stated wind speeds are indicative and require validation.

5 PRELIMINARY WIND FARM DESIGN

5.1 Introduction

The FOWIND consortium has completed a review of potential wind turbine offerings for the Gujarat Region, given a commercial turbine procurement date target of 2020. The objective of this exercise is to review the suitability of these wind turbine offerings considering the key drivers for wind turbine selection, specifically:

- Site suitability (ability to withstand the site climatic conditions over the design operating life);
- WTG track record (a loose measure of wind turbine reliability);
- Suitability of wind turbine to the site foundation selection; and
- Site specific power production (which contributes significantly towards the cost of energy).

It should be noted that this section is not a full 'Levelised Cost of Energy' assessment and, as such, only considers the factors mentioned above. Assuming a wind turbine is technically suitable for the site, the optimal wind turbine selection will result in the lowest cost of energy for the project.

Finally this section presents results from a high level energy production assessment for each of the identified zones in Gujarat.

5.2 Summary of commercially available wind turbines

Table 5 presents the characteristics of wind turbines that should be commercially available assuming a procurement date target of 2020. Only wind turbines greater than 3.0 MW in rated capacity have been identified.

Table 5: Potential offshore turbines for the Gujarat selected zones.

Turbine Model	Rated Power[1] (MW)	IEC Class	Rotor diameter (m)	Commercial Timeline [2]
(Alstom) Haliade 150-6	6.0	IEC IB	150.0	2014
AMSC Titan	10.0	TBC[4]	190.0	TBC[4]
Areva M5000-135	5.0	Targeting IEC IB & S	135.0	2013
Areva M8000-180	8.0	TBC[4]	180	2018
CSIC HZ 127-5MW	5.0	Targeting IEC IA	127.0	2014
CSIC HZ 151-5MW	5.0	Targeting IEC IIIB	151.0	2015
CSR WT5000-D128	5.0	Targeting IEC IB	128.0	2014
DOOSAN WinDS3000	3.0	Targeting IEC IA	91.3	TBC[4]
Gamesa G128-5.0	5.0	IEC IB	128.0	2013
Gamesa G132-5.0	5.0	Targeting IEC S	132.0	2013
Gamesa G14X-7.0	7.0	TBC[4]	140.0	2015
Goldwind GW 6MW	6.0	TBC[4]	TBC[4]	2014
GUP6000-136	6.0	TBC[4]	136.0	2012
Hitachi HTW 5.0-126	5.0	Targeting IEC S	126.0	2015
Huayi 6MW	6.0	TBC[4]	TBC[4]	TBC[4]
Hyundai HQ5500	5.5	IEC IB	127.0	2014
Mervento 3.6-118	3.6	IEC IIA	118.0	2012

Turbine Model	Rated Power[1] (MW)	IEC Class	Rotor diameter (m)	Commercial Timeline [2]
Mervento 4.0-118	4.0	IEC IIB	118.0	2014
MHI Vestas V112-3.3MW	3.3	IEC IB	112.0	2014
MHI Vestas V112-3.3MW	3.3	IEC IIIB	126.0	2014
MHI Vestas V164-8.0MW	8.0	IEC S (based on IEC IB)	164.0	2015
Ming Yang 6MW SCD	6.0	TBC[4]	140.0	TBC[4]
Senvion 6M	6.1	IEC IB	126.0	2012
Senvion 6M+	6.2	IEC S (based on IEC IB)	152.0	2014
Shanghai electric SE 3.6MW	3.6	TBC[4]	122.0	2010
Shanghai electric SE 5.0MW	5.0	TBC[4]	TBC[4]	TBC[4]
Siemens SWT-3.6-120	3.6	IEC IA	120.0	2011
Siemens SWT-3.6-130	3.6	IEC IB	130.0	2015
Siemens SWT-4.0-120	4.0	IEC IA	120.0	2014
Siemens SWT-4.0-130	4.0	IEC IB	130.0	2014
Siemens SWT-6.0-154	6.0	IEC IA	154.0	2014
Sinovel SL6000/128	6.0	Targeting IEC I	128.0	2011
Sinovel SL6000/155	6.0	TBC[4]	128.0	2011
XEMC Darwind DD115	5.0	Targeting IEC IC	115.0	2013
Yinhe Windpower	3.5	TBC[4]	93.2	TBC[4]
Zhejiang Windey WWD130/.5000	5.0	TBC[4]	130.0	TBC[4]

1. This value is based on the nameplate rated power rather than the peak power of the power curve.
2. Estimated full commercial availability on the basis of public domain information.
3. This is the rotor productivity at rated power of the turbine.
4. TBC refers to a turbine characteristic that is "To Be Confirmed" and not yet publically reported by the wind turbine manufacture

5.3 Review of climatic conditions in the Gujarat region

Currently available offshore wind turbines are designed and certified against International Electro-technical Commission (IEC) requirements (or a variant of), which principally represent European environmental conditions. It is of note that the IEC 61400 edition 3 Standard states;

"The particular external conditions defined for classes I, II and III are neither intended to cover offshore conditions nor wind conditions experienced in tropical storms such as hurricanes, cyclones and typhoons. Such conditions may require wind turbine class S design."

Hence, utilising an existing wind turbine design for India requires careful consideration of the environment in which it operates and will ultimately require discussions with wind turbine suppliers. However, at this pre-feasibility stage it is important to focus on the critical environmental considerations which may preclude wind turbine suitability, namely normal and extreme operating conditions.

The IEC 61400-1 standard, provides a classification of turbines accordingly to site wind conditions. Turbines are classed by three main parameters: the average wind speed, extreme 50-year gust, and turbulence. Table 6 shows the wind turbine classes described in this standard.

Table 6: Wind Turbine Classes.

WTG classes	I	II	III	IV	S
Reference wind speed, U_{ref}	50	42.5	37.5	30	Values specified by the manufacturer
Annual avg. wind speed $U_{avg} = 0.2 \times U_{ref}$	10	8.5	7.5	6.0	
50 year return gust speed,$1.4 \times U_{ref}$	70	59.5	52.5	42	
Turbulence classes	A	B			
I_{15} characteristic turbulence intensity at 15m/s	18%	16%			

Mean wind climate

The estimated mean annual wind speed, at 100 m MSL, for the identified wind farm development zones, ranges between 6.7 m/s and 7.0 m/s. According to IEC 61400 this equates to a requirement for wind turbines which will be certified on a site-specific basis to IEC Class III and above.

Extreme wind climate

A very important aspect of the climate of Gujarat is the risk of cyclonic conditions. Gujarat falls under the region of tropical cyclones. Most of the cyclones affecting the Gujarat State are generated in the Arabian Sea. They move north-east and hit the coast particularly the Southern Kutch and Southern Saurashtra and the Western part of Gujarat. The region experiences two cyclonic storm seasons: May to June (advancing southwest monsoon) and September to November (retreating monsoon). Figure 4 presents a map showing the path of cyclones in the Gujarat Region over the period 1946 to 2007.

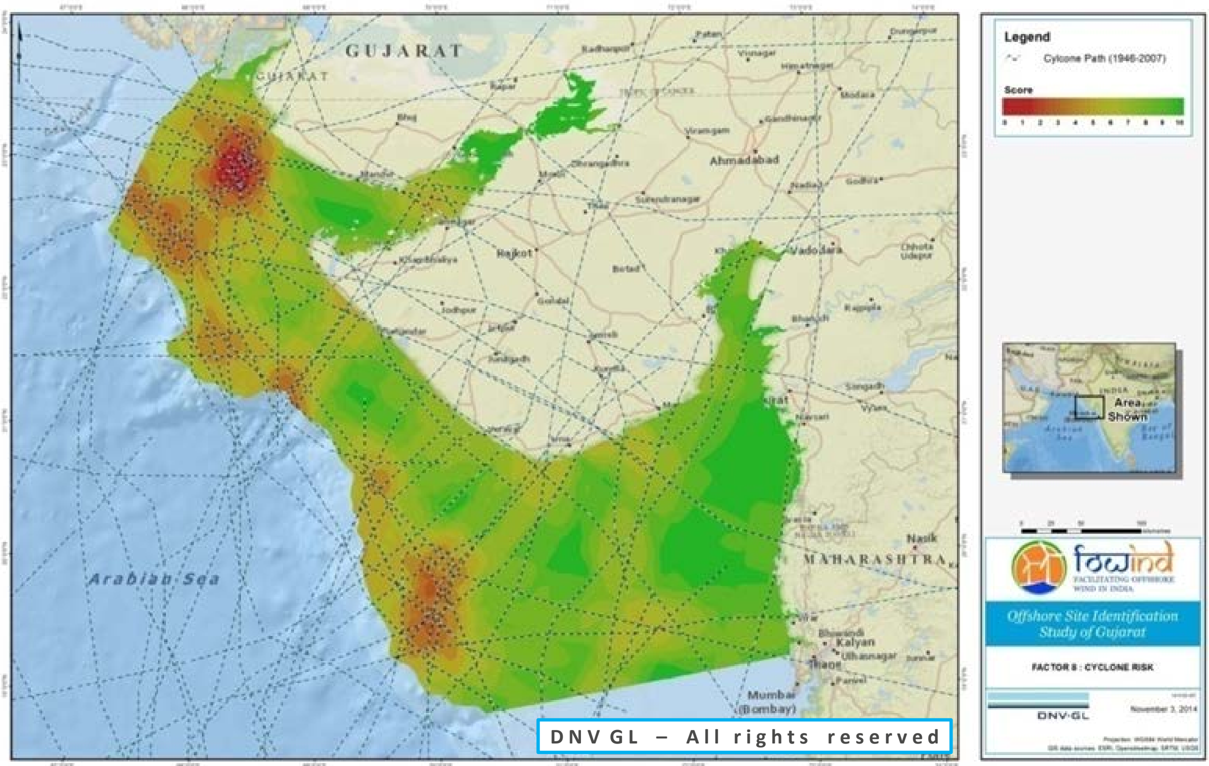


Figure 4: Path of cyclone in the Gujarat Region for the period 1946 to 2007.

To assess the extreme wind conditions at the site, specifically focused on 50-year return period, best practice would dictate that 10-years of hub-height wind measurements be supplied at the proposed project site, from which a statistical analysis of the extreme wind speed with fixed return periods can be conducted. However, no long-term hub-height wind measurements are available in the Gujarat region.

In lieu of measurements, it has been possible to estimate a 50-year return gust wind speed using the Indian Standard relating to Codes of Practice for Design Loads for Buildings and Structures (IS 875-3 [19]). This document has been designed primarily for onshore structures and its application offshore is subject to significant uncertainty.

Figure 5 presents the cyclone hazard zoning along with the basic wind speed in Gujarat according to IS 875-3. Saurashtra coast, specifically in Porbandar, Jamnagar and Junagadh districts, are exposed to high intensity cyclonic and storm impact. The colours on the map on the top right of the image correspond to a base wind speed which is a peak gust wind speed, averaged over a period of about 3 seconds, corresponding to 10 m height above the mean ground level in open terrain.

The Standard Method is used, employing the following definitions:

- The basic wind speed, V_b, is obtained from a supplied map of maximum gust (3-second average) wind speeds, independent of direction, at a height of 10 m above level terrain, with a probability of 0.02 being exceeded in any one year.
- For the identified zones A to F, the basic wind speed of the coast of Gujarat is somewhere in the region of 39 m/s to 50 m/s. For zones G & H, the basic wind speed is in excess of 55 m/s.
- The site wind speed, V_s, is estimated by applying factors to account to variation in height and exposure of the site. Extrapolating to 100 m MSL and off the coast relies on estimated factors of 1.176 and 1.150 respectively, resulting in an estimated site gust wind speed of 67.6 m/s for zones A to F and 74.4 m/s for zones G & H.

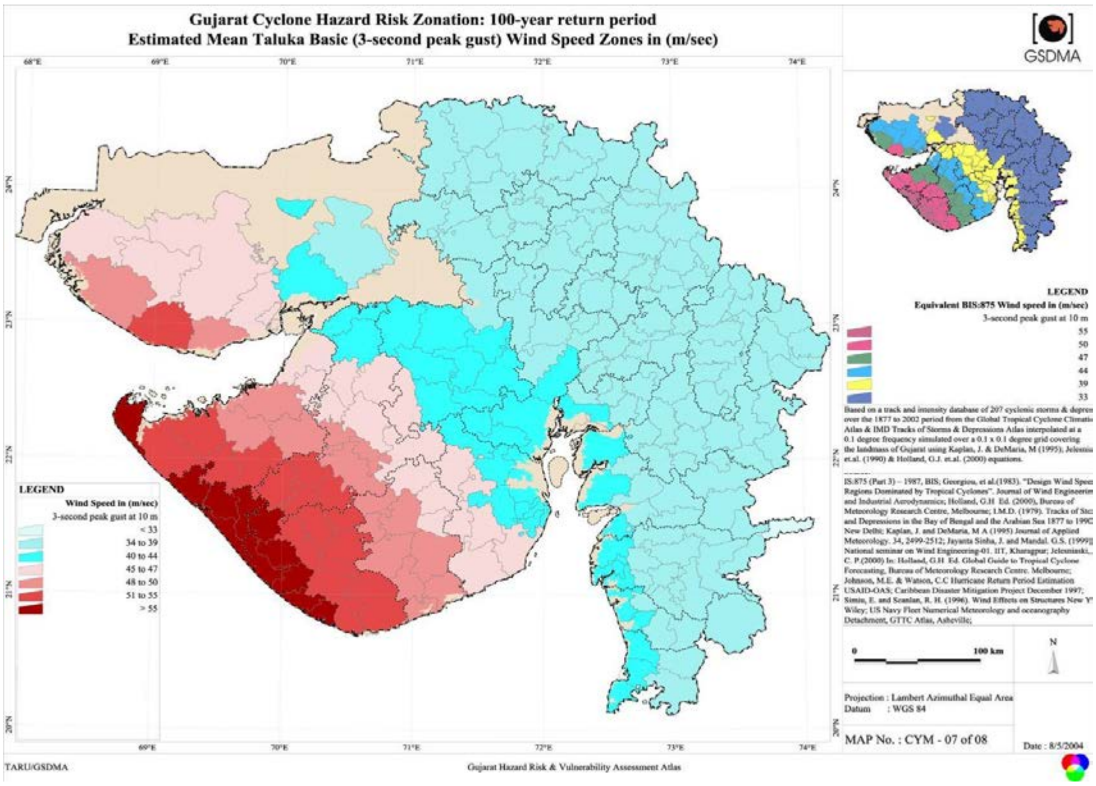


Figure 5: Cyclone Hazard Zone & the Basic Wind Speed in Gujarat.
Source: [20]

Examination of Table 6 indicates that these conditions are very close to (zones A to F), or exceed (zones G & H), IEC Class I limitations. More detailed extreme wind speed studies are recommended to verify this preliminary analysis.

It should also be noted that the design of wind turbines for cyclone conditions requires consideration of fast-changing, twisted wind shear profiles combined with sudden changes in wind direction and flow inclination, common in extreme situations. These conditions create additional loading on the turbines; therefore, some areas that are subjected to typhoons which produce maximum wind speeds less than those relating to IEC Class I may still be unsuitable, even when considering a Class I turbine. The added risk due to this can be reduced by the turbine manufacturer taking on the operation and maintenance risk for periods where the extreme wind speeds are above the design conditions or some limited curtailment could also be implemented during these periods.

Further review of the site conditions may prove that turbines taken forward for any future project will likely require "Class S" certification. The alternative approach (one which has been used in the USA) is for the manufacturer to provide a warranty for the wind turbine up to the design class (in this case Class I), and to supplement the manufacturer's warranty with insurance to extend the cover up to typhoon conditions. This approach will need as a minimum a single met mast with wind speed measurement at hub height, to determine the wind speed experienced by the wind farm.

Classification of a wind turbine as Class A or B is dependent on the turbulence level within the wind farm. This will be mainly driven by wind turbine array layout and can be quantified and mitigated at a later stage.

Based on the above assessment, Class I or S wind turbines have been taken forward for further assessment. Where wind a turbine's classification is currently unknown, it has been removed.

5.4 Site specific power production

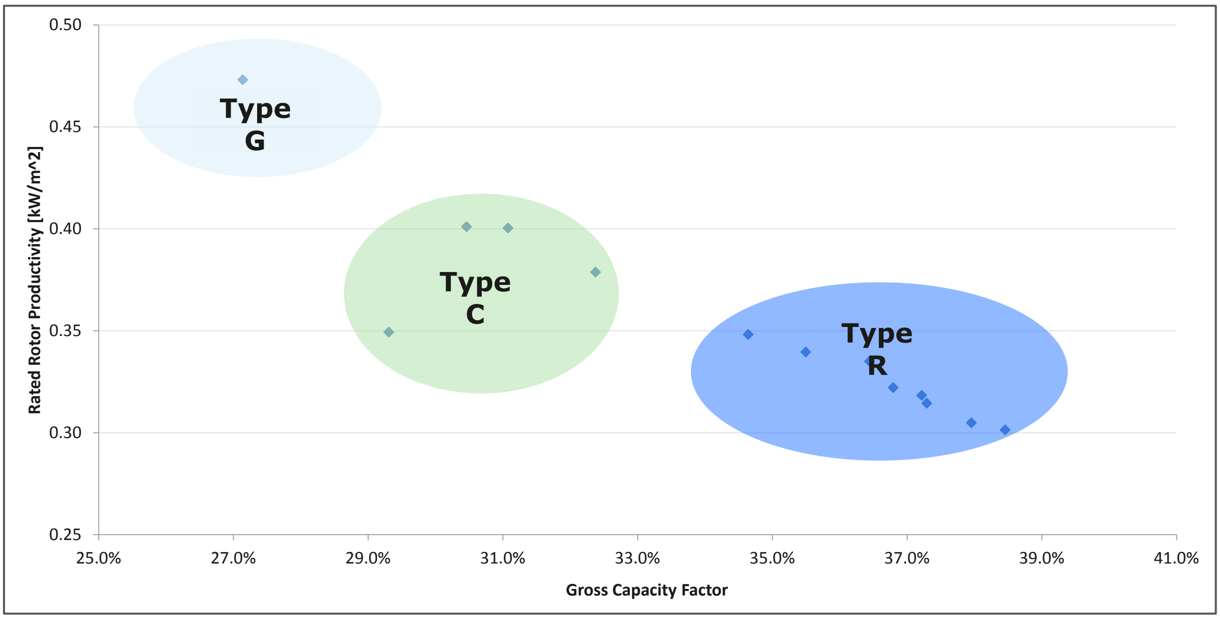
The two primary design parameters for wind turbines can be considered to be the size of the rotor and the capacity of the turbine electrical design. Both of these parameters can be regarded to be a constraint on production. At low wind speeds the maximum amount of energy that can be generated is limited by the size of the area from which the turbine can capture the free flowing energy in the wind (the rotor). At higher wind speeds, it is the wind turbine electrical design which constrains the amount of power that can be produced (the generator).

It can be considered that the interrelationship between the above mechanical and electrical characteristics and their costs will determine the optimal turbine design for a given site. The estimated mean annual wind speed at 100 m MSL for the identified wind farm development sites ranges between 6.7 m/s and 7.0 m/s. This is considered to be a low mean wind speed for offshore sites, by Northern European standards, therefore generated energy is thus limited by the swept area of the rotor.

Figure 6 and Figure 7 depict the performance of a sub-selection of wind turbine offerings from Table 5 in terms of wind turbine Gross Capacity Factor (which does not include any energy losses, wake, electrical, etc.) and Rated Rotor Productivity, considering both lowest and highest mean wind speed estimates for the zones identified within the Gujarat Region. Rated Rotor Productivity is used to assess the performance of the wind turbine rotor as a function of its rated power. A larger value indicates a machine which has a small rotor to generator size and a lower value indicates the opposite. Ignoring the influence of a wind turbine control system, it is general for machines with a lower Rated Rotor Productivity metric to have a higher wind turbine Capacity Factor at low wind speeds.

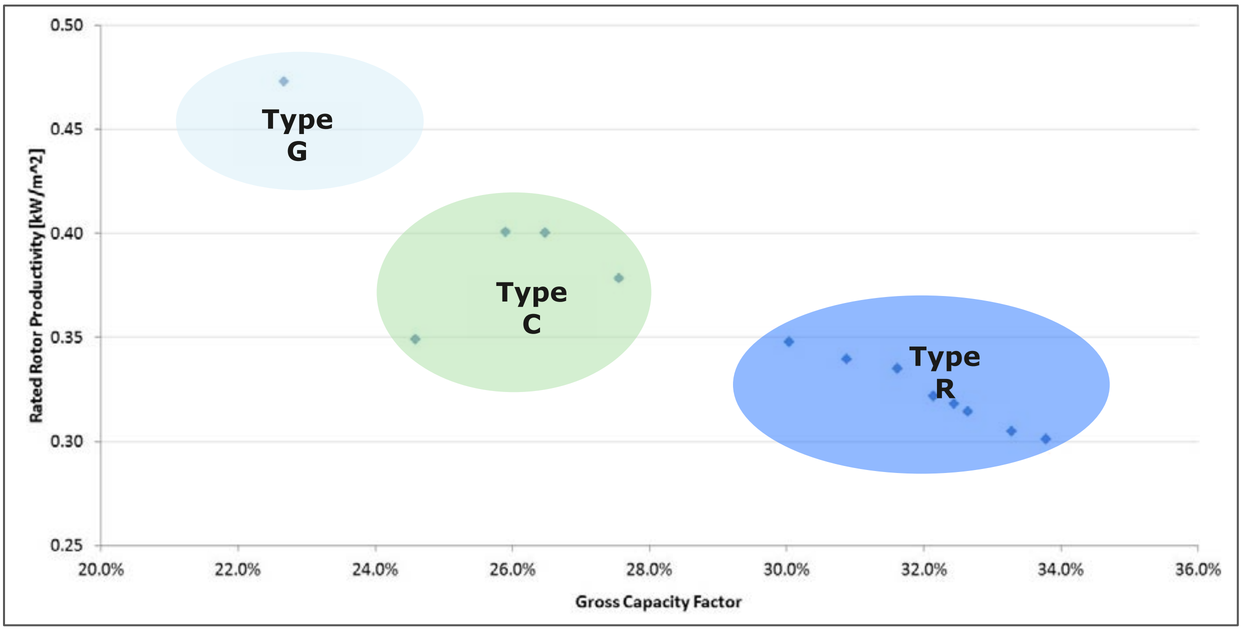
It can be seen that turbines can be grouped into the following performance categories;

- A ***large* Rotor** to small generator ratio (Defined here as 'Type **R**');
- A small rotor to ***large* Generator** ratio (Defined here as 'Type **G**'); and;
- A **Central** case between the two above extremes (Defined here as 'Type **C**').



Notes: Wake losses and losses in the wind farm electrical systems have not been taken into account.

Figure 6: Wind turbine Gross Capacity Factor against Rated Rotor Productivity. (7.0 m/s Mean Annual Wind Speed at 100 m MSL)



Notes: Wake losses and losses in the wind farm electrical systems have not been taken into account.

Figure 7: Wind turbine Gross Capacity Factor against Rated Rotor Productivity. (6.7 m/s Mean Annual Wind Speed at 100 m MSL)

In Northern Europe, an offshore gross capacity factor of 55% would be expected in order to achieve Project Net Capacity Factors in the order of 40% to 45%, once all losses have been taken into consideration. It is noted that, due to the lower wind speed conditions in the Gujarat Region, gross capacity factors of between 23% and 39% are estimated.

In order to likely achieve the best possible project return, a project in the Gujarat Region will have to consider a Type R wind turbine with a large rotor to a small generator ratio. Based on the above, the FOWIND consortium has only considered wind turbines that have a Rated Rotor Productivity lower than 0.35 kW/m^2 and which fall under the Type R category, as presented in Table 5.

Table 7 presents the shortlisted wind turbines for the identified Gujarat zones, following the climatic conditions down-selection. Those highlighted are recommended to be taken forward for further consideration. Table 7 also presents two generic wind turbines which have been taken forward for further analysis in this report. These generic wind turbines have been developed to be representative of the likely commercial offerings available to potential projects in the region.

Table 7: Type R shortlisted wind turbines for the Gujarat zones.

Turbine Model	Rated Power[1] (MW)	IEC Class	Rotor diameter (m)	Commercial Timeline [2]	Rated Rotor Productivity [3] (kW/m^2)
(Alstom) Haliade 150-6	6.0	IEC IB	150.0	2014	0.34
Areva M5000-135	5.0	Targeting IEC IB & S	135.0	2013	0.35
CSIC HZ 127-5MW	5.0	Targeting IEC IA	127.0	2014	0.39
CSR WT5000-D128	5.0	Targeting IEC IB	128.0	2014	0.39
DOOSAN WinDS3000	3.0	Targeting IEC IA	91.3	TBC	0.46
Gamesa G128-5.0	5.0	IEC IB	128.0	2013	0.39
Gamesa G132-5.0	5.0	Targeting IEC S	128.0	2013	0.37
Hitachi HTW 5.0-126	5.0	Targeting IEC S	126.0	2015	0.40
Hyundai HQ5500	5.5	IEC IB	127.0	2014	0.43
MHI Vestas V112-3.3MW	3.3	IEC IB	112.0	2014	0.26
MHI Vestas V164-8.0MW	8.0	IEC S (based on IEC IB)	164.0	2015	0.38
Senvion 6M	6.1	IEC IB	126.0	2012	0.49
Senvion 6M+	6.2	IEC S (based on IEC IB)	152.0	2014	0.34
Siemens SWT-3.6-120	3.6	IEC IA	120.0	2011	0.32
Siemens SWT-3.6-130	3.6	IEC IB	130.0	2015	0.27
Siemens SWT-4.0-120	4.0	IEC IA	120.0	2014	0.35
Siemens SWT-4.0-130	4.0	IEC IB	130.0	2014	0.30
Siemens SWT-6.0-154	6.0	IEC IA	154.0	2014	0.32
Sinovel SL6000/128	6.0	Targeting IEC I	128.0	2011	0.47
XEMC Darwind DD115	5.0	Targeting IEC IC	115.0	2013	0.48
Generic 4MW	4.0	-	120.0	-	0.35
Generic 6MW	6.0	-	154.0	-	0.32

Notes:

1 This value is based on the nameplate rated power rather than the peak power of the power curve.
2 Estimated commercial availability on the basis of public domain information.
3 This is the rotor productivity at rated power of the turbine.

5.5 Wind turbine track record

The offshore track record of a wind turbine generator (WTG) indicates the level of maturity of a turbine with higher levels of experience preferred to turbines without a significant track record. An ideal metric corresponding to this element of selection process is 'turbine offshore operating months' and for a specific WTG, this metric directly measures the cumulative number of months of all turbines that have been installed and operating in an offshore environment and is portrayed in Figure 8.

Only WTG orders where contracts have been signed to date are included in Figure 8 and WTG models with no orders are not depicted. It should be noted that prototypes are not included in the analysis; however they are inserted into Figure 8 as milestones.

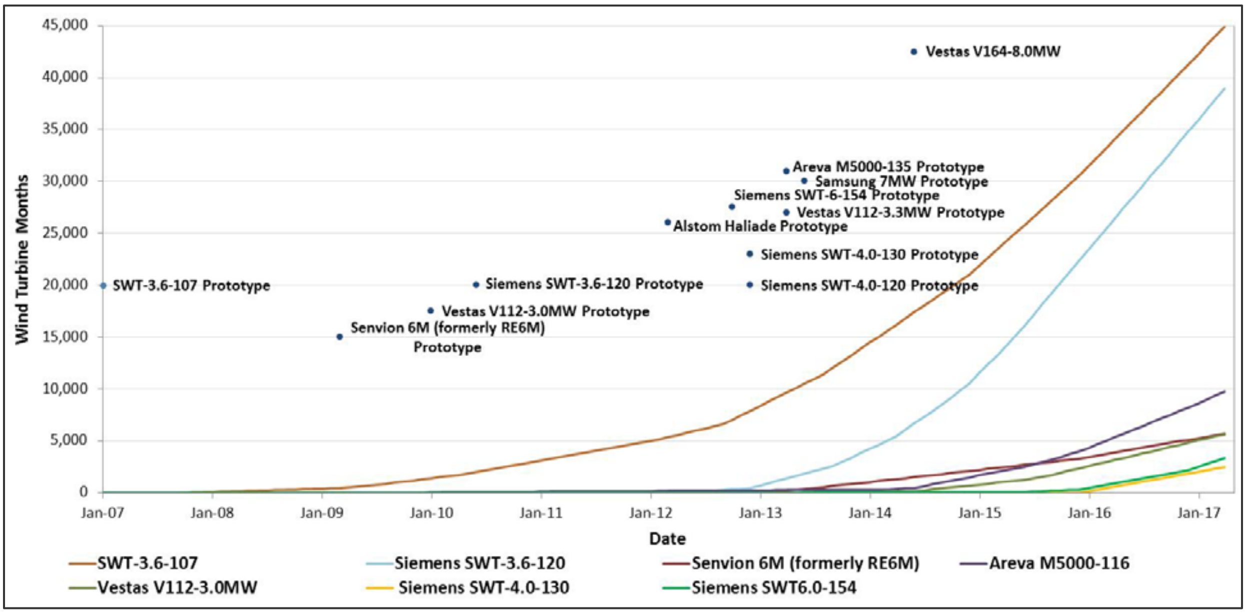


Figure 8: Offshore turbine track records and prototype commissioning dates.

In certain cases, turbine manufacturers produce WTG platforms which are installed both onshore and offshore and it can prove useful to assess the accrued onshore experience, however offshore operational experience is more relevant. In this regard, it should be noted the Vestas V112-3MW platform has substantial onshore experience with 973 units delivered to customers as of 31st Dec 2013 [21].

Furthermore, when assessing WTG track record, multiple products can be available on a single turbine platform. A turbine platform is a 'family' of turbines all based on the same underlying core technology with some important variants between models which typically manifests itself principally in the size of the rotor and the capacity of the turbine electrical design. For example, the Siemens SWT-3.6-107, SWT-3.6-120, SWT-4.0-120 and SWT-4.0-130 are all based on the same underlying core design and technology and the track record of each machine augments the track record of the turbine platform as a whole. Similar to Siemens Platform 4, the Vestas V112-3MW platform counts with relevant onshore experience. Figure 9 depicts these two WTG 'platforms' as two of the most proven turbines in the market at the moment of writing this report.

It can be seen from Figure 9 that Siemens G4 platform will have accrued a substantially stronger track record than the other WTG's under consideration with the Vestas V112-3MW platform (including onshore experience) coming in second place.

A strong track record may come at a price premium and it should be noted that there may be opportunities to partner with organisations which are bringing new WTG's to the market. This may result in more favourable economic conditions with respect to turbine procurement in return for sharing the risk associated with the lack of a proven offshore track record.

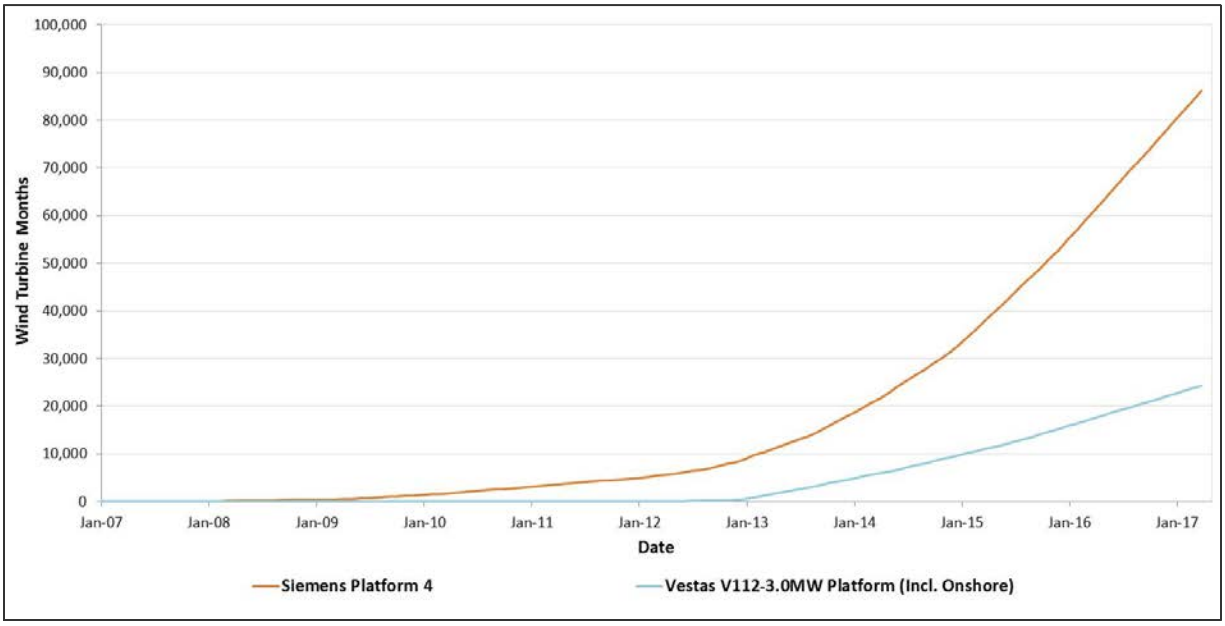


Figure 9: Offshore platform track records in wind turbine operating months (Siemens and Vestas examples).

5.6 Wind turbine foundation considerations

At this early stage in the project development, there is limited data available on the ground conditions across the eight identified zones. Based on the limited data available and with reference to Section 6.1, it is understood that monopile, tripod and jacket foundation solutions could be viable across these sites. At this early stage, it is therefore not considered that foundation options will preclude a particular wind turbine type. However, more detailed assessments may result in certain turbine sizes being ruled-out.

5.7 Zone level energy production

The FOWIND consortium has conducted a high level energy production assessment for each of the identified zones in Gujarat. The assessment was undertaken assuming uniform layouts for both 150 MW and 504 MW wind farm capacity options, using the generic 4 MW and 6 MW wind turbines described in Section 5.4.

The wind climate has been estimated for each of the zones using preliminary modelling from DNV GL's WindFarmer wake model to estimate wake losses. Following this, a number of energy loss factors have been assessed either through estimation or assumption, in order to provide net annual energy production estimates, as described below. Cases where important potential sources of energy loss have been deliberately omitted from consideration have been clearly identified in the following sub-sections. The derived loss factors have been considered as independent energy production efficiencies throughout.

5.7.1 Array efficiency (Internal wake estimates)

In light of operational evidence, there is considerable uncertainty associated with the prediction of wake losses within large offshore wind projects. In addition, there is a wide variety of approaches available to the industry to provide such predictions.

DNV GL's WindFarmer Large Wind Farm Model has been adopted for the determination of wake losses in the Gujarat region, which is built upon an Eddy Viscosity Model. For the purposes of this study, a constant spacing between turbines of 8 rotor diameters for the 150 MW wind farm capacity scenario and 7 rotor diameters for the 504 MW scenario has been assumed to estimate wake losses.

5.7.2 Wind farm availability

This factor represents the expected energy-based average turbine availability over the operational lifetime of the project including the Balance of Plant availability. The Balance of Plant of the wind farm covers the availability of: inter-turbine cables, offshore substations, export cables and the onshore substation infrastructure up to the point of connection to the grid. The availability is defined as the net production after turbine and balance of plant downtime has been taken into account, with respect to the net production assuming all turbines and balance of plant equipment are operating all of the time and is typically quoted as a percentage.

It is noted that the availability estimates are generic in nature. Review of the specific turbine model, O&M arrangements, O&M budgets and warranties are not included within this pre-feasibility study. The estimations presented here are subject to amendment as more information becomes available on the O&M provision for a wind farm in the Gujarat Region. For the purposes of this assessment, the DNV GL in-house model "O2M" has been used to estimate the wind turbine availability at each zone and for each project configuration as detailed in Section 6.4.6.

5.7.3 Electrical efficiency

There will be electrical losses experienced between the high voltage terminals of each of the wind turbines and the metering point. This factor defines the electrical losses encountered when the project is operational, which will manifest themselves as a reduction in the energy measured by an export meter. This is presented as an overall electrical efficiency and is based on the long-term average expected production pattern of the project. DNV GL has estimated this efficiency as a function of electrical concept and distance from grid as detailed in Table 8 to Table 11.

It should be noted that the electrical losses applied should be considered to the point where the revenue meter will be installed. It is unclear where that location would be, given the early stage in the project development. The choice of metering point will be highly dependent on where responsibilities lie for the provision of the export electrical system. For example, in the German Offshore Market, responsibility is placed on the transmission system operator to provide on offshore connection point to wind farms developed in German Federal waters.

The FOWIND consortium recommends that a formal calculation of the electrical loss should be undertaken when the electrical system has been defined in greater detail.

5.7.4 Wind Farm Performance

The performance of wind farm can be affected by many different factors which include:

- Blade degradation: The accretion of dirt or salt, which may be washed off by rain from time to time, as well as physical degradation of the blade surface over prolonged operation.
- Wind sector management: Wind sector management is a form of wind farm control in which selected wind turbines are curtailed or shut down under specified wind conditions in order to reduce operational loads experienced by the WTGs and their support structures when high wind speeds coincide with high levels of turbulence. A commonly applied form of wind sector management is "alternate shut down" whereby every alternate machines within a row is shut down when the wind sector management wind speed and direction criteria are met. For example, WTGs 2, 4, 6, 8, etc. may be shut down. No wind sector management scheme is proposed nor, from the layout design, does the FOWIND consortium consider one likely to be necessary. Therefore, no deductions have been made for this potential source of energy loss.

- Project power consumption: This factor defines the electrical efficiency due to the electrical consumption of the project during periods of non-operation due to transformer no load losses and consumption by electrical equipment within the turbines and substation. For most projects this factor may be neglected and considered as an operational cost rather than an electrical efficiency factor. However, for some metering arrangements it may be appropriate to include this as an electrical efficiency factor.
- Grid availability: This factor defines the expected grid availability for the project. It is stressed that this factor relates to the grid being outside the operational parameters defined within the grid connection agreement as well as actual grid downtime. This factor also accounts for delays in the project coming back to full operation following a grid outage. A typical assumption for generic projects in Europe is 99.5 %, however, grid availability in India could have different behaviours and therefore this value should be regarded with caution.
- High wind hysteresis losses: Wind turbines will shut down when the wind speed exceeds a certain limit. High wind speed shut down events can cause significant fatigue loading. Therefore to prevent repeated start up and shut down of the turbine when winds are close to the shutdown threshold, hysteresis is commonly introduced into the turbine control algorithm. Where a detailed description of the wind turbine cut-in and cut-out parameters are available, this is used to estimate the loss of production due to high wind hysteresis by repeating the analysis using a power curve with a reduced cut-out wind speed. Due to the low wind conditions expected at all sites, the FOWIND consortium has assumed these losses to be negligible.
- Power curve compliance: Wind turbines will have some sub-optimal efficiencies when considering the power curves provided by the manufacturer. These inefficiencies are due to different factors such as pitch/yaw misalignment, controller performance, etc. For this reason, DNV GL typically assumes a power curve compliance efficiency of 99.5 %.

After consideration of all the factors mentioned above, DNV GL has assumed an overall Wind Farm Performance availability of 98.0% for all different scenarios.

5.7.5 Energy production summary

The projected energy production for each of the proposed projects is summarised below. These results represent an estimate of the annual production expected over the lifetime of the project assumed to be 20 years.

Table 8: Summary of energy production estimates for the Gujarat zones for a 150 MW wind farm (generic 4 MW turbine).

Project scenario	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	
Turbine model	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	
Project capacity	150	150	150	150	150	150	150	150	MW
Hub height	80	80	80	80	80	80	80	80	(m) MSL
Mean Annual Wind Speed	6.9	6.8	6.7	6.6	6.8	6.6	6.6	6.6	(m/s)
Gross energy output	435.8	422.3	401.6	395.5	423.9	391.6	375.7	378.9	GWh/annum
Array efficiency[1]	88.3%	88.2%	87.9%	87.8%	88.2%	87.7%	87.2%	87.3%	DNV GL estimate
Wind farm availability[2]	94.4%	94.6%	94.5%	94.7%	94.2%	94.7%	89.8%	91.3%	DNV GL estimate
Electrical efficiency[3]	97.1%	97.1%	97.6%	97.5%	95.8%	97.3%	97.5%	97.4%	DNV GL estimate
Wind farm performance[4]	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	DNV GL assumption
Net Energy Output	**345.4**	**335.1**	**318.9**	**313.9**	**330.5**	**310.3**	**281.1**	**288.4**	**GWh/annum**
Project Net Capacity Factor	**25.9%**	**25.2%**	**23.9%**	**23.6%**	**24.8%**	**23.3%**	**21.1%**	**21.6%**	

Notes:

1 Internal wake losses
2 Includes assumed Balance of Plant (BoP) availability
3 Includes array and export cable losses
4 Includes sub-optimal efficiencies (power curve compliance, blade degradation, power consumption, grid availability, etc.)

Table 9: Summary of energy production estimates for the Gujarat zones for a 150 MW wind farm (generic 6 MW turbine).

Project scenario	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	
Turbine model	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	
Project capacity	150	150	150	150	150	150	150	150	MW
Hub height	100	100	100	100	100	100	100	100	(m) MSL
Mean Annual Wind Speed	7.0	6.9	6.8	6.7	6.9	6.7	6.7	6.7	(m/s)
Gross energy output	480.0	468.9	450.2	445.6	464.5	438.5	420.4	420.4	GWh/annum
Array efficiency	90.7%	90.6%	90.4%	90.4%	90.6%	90.3%	89.8%	89.8%	DNV GL estimate
Wind farm availability	94.4%	94.6%	94.5%	94.6%	94.2%	94.7%	89.7%	91.0%	DNV GL estimate
Electrical efficiency	97.0%	97.0%	97.5%	97.4%	95.8%	97.2%	97.4%	97.4%	DNV GL estimate
Wind farm performance	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	DNV GL assumption
Net Energy Output	**390.6**	**382.2**	**367.6**	**363.7**	**371.9**	**357.0**	**323.5**	**327.9**	**GWh/annum**
Project Net Capacity Factor	**29.7%**	**29.1%**	**28.0%**	**27.7%**	**28.3%**	**27.2%**	**24.6%**	**24.9%**	

Notes:

1 Internal wake losses
2 Includes assumed Balance of Plant (BoP) availability
3 Includes array and export cable losses
4 Includes sub-optimal efficiencies (power curve compliance, blade degradation, power consumption, grid availability, etc.)

Table 10: Summary of energy production estimates for the Gujarat zones for a 504 MW wind farm (generic 4 MW turbine).

Project scenario	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	
Turbine model	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	4.0 MW	
Project capacity	150	150	150	150	150	150	150	150	MW
Hub height	80	80	80	80	80	80	80	80	(m) MSL
Mean Annual Wind Speed	6.9	6.8	6.7	6.6	6.8	6.6	6.6	6.6	(m/s)
Gross energy output	1444.9	1400.2	1331.5	1311.3	1405.4	1298.6	1245.6	1256.4	GWh/annum
Array efficiency	78.4%	78.1%	77.6%	77.5%	78.1%	77.4%	76.5%	76.6%	DNV GL estimate
Wind farm availability	94.1%	94.6%	94.1%	94.6%	94.1%	94.6%	89.6%	92.4%	DNV GL estimate
Electrical efficiency	97.1%	97.1%	97.6%	97.0%	95.8%	97.3%	97.5%	97.0%	DNV GL estimate
Wind farm performance	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	DNV GL assumption
Net Energy Output	**1013.5**	**984.2**	**929.7**	**913.3**	**970.3**	**906.1**	**816.5**	**845.1**	**GWh/annum**
Project Net Capacity Factor	**22.9%**	**22.3%**	**21.0%**	**20.7%**	**22.0%**	**20.5%**	**18.5%**	**19.1%**	

Notes:

1 Internal wake losses
2 Includes assumed Balance of Plant (BoP) availability
3 Includes array and export cable losses
4 Includes sub-optimal efficiencies (power curve compliance, blade degradation, power consumption, grid availability, etc.)

Table 11: Summary of energy production estimates for the Gujarat zones for a 504 MW wind farm (generic 6 MW turbine).

Project scenario	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	
Turbine model	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	6.0 MW	
Project capacity	150	150	150	150	150	150	150	150	MW
Hub height	100	100	100	100	100	100	100	100	(m) MSL
Mean Annual Wind Speed	7.0	6.9	6.8	6.7	6.9	6.7	6.7	6.7	(m/s)
Gross energy output	1612.8	1575.7	1512.8	1497.4	1560.8	1473.2	1412.7	1412.7	GWh/annum
Array efficiency	81.5%	81.3%	80.9%	80.8%	81.2%	80.7%	79.8%	79.8%	DNV GL estimate
Wind farm availability	94.3%	94.7%	94.6%	94.9%	94.0%	94.9%	90.0%	92.5%	DNV GL estimate
Electrical efficiency	97.0%	97.0%	97.5%	96.9%	95.8%	97.2%	97.4%	96.9%	DNV GL estimate
Wind farm performance	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	98.0%	DNV GL assumption
Net Energy Output	**1177.8**	**1152.9**	**1105.7**	**1090.2**	**1117.4**	**1073.9**	**969.3**	**990.3**	**GWh/annum**
Project Net Capacity Factor	**26.7%**	**26.1%**	**25.0%**	**24.7%**	**25.3%**	**24.3%**	**21.9%**	**22.4%**	

5 PRELIMINARY WIND FARM DE-
SIGN

Notes:

1 Internal wake losses
2 Includes assumed Balance of Plant (BoP) availability
3 Includes array and export cable losses
4 Includes sub-optimal efficiencies (power curve compliance, blade degradation, power consumption, grid availability, etc.)

Table 8 to Table 11 include potential sources of energy loss that have been estimated or assumed. The methods used to calculate losses, the losses for which assumptions have been necessary and those losses which have not been considered are discussed in Section 5.7. It is recommended that the various loss factors are reviewed and considered carefully.

5.7.6 Energy production estimate uncertainties

The following uncertainties have been identified as important to the analysis of the wind farm layouts undertaken:

- The wind climate predicted by DNV GL in this study is subject to significant uncertainties given the input data and methods employed. In particular, errors in the long-term wind rose will affect layout optimisation, given the uni-directional nature of the wind rose;
- Further to the estimated losses, DNV GL has made several generic or typical assumptions to be able to perform the present analysis; therefore, these values must be taken as indicative and subject to changes according to the final plant configuration;
- The prediction of wake losses for large offshore wind farms is an area of significant uncertainty and although a correction has been applied to the analysis to take account of recent operational evidence, it should be noted that wake models used in this analysis may be updated in the future, in light of new analytical developments or empirical data.

For the purpose of this study, it has been assumed that there are no planned wind farms in the immediate vicinity of any of the identified sites. Given the immaturity of the market it is not considered appropriate to account for reduction in yield due to the presence of other wind farms.

6 PRELIMINARY TECHNICAL CONSIDERATION FOR EACH ZONE

6.1 High level foundation and geotech screening study

6.1.1 Introduction

The objective of this section is to further investigate the suitability of different market ready offshore wind turbine foundation types (see Section 6.1.2). An initial foundation screening study will be conducted with respect to the available site-specific conditions found in each identified development zone (from Section 34). Offshore wind foundations are complex structures that must for example resist:

- High dynamic wind turbine loads resulting in significant fatigue loads within members and joints;
- Cyclic soil loading and large lateral load transfer through pile-soil interaction (significant overturning moments);
- Hydrodynamic loading from waves and currents;
- Extreme typhoon loads; and
- Earthquake loading in some regions with potential for soil liquefaction.

In addition to this complex loading, the "design problem" will be compounded in the future with the industry developing towards larger MW class turbines with increased loads.

Offshore wind foundations typically make up 15-25% of an offshore wind project's capital expenditure (CapEx) cost and due to their site-specific nature (when compared to the wind turbine) provide a worthy opportunity for cost reduction. Cost optimisation for foundations can be two-fold; (1) selecting the most suitable foundation type from the first step, and, (2) implementing a progressive and integrated design process to ensure an optimised design (see Section 6.1.3). This high level screening study will consider the key factors that influence foundation choice, including:

- Cost;
- Water Depth;
- Wind Turbine MW Class and Frequency Window effects;
- Ground Conditions;
- Local Installation Vessel Availability;
- Local Fabrication Capability;
- Extreme Wind Speeds (Typhoons); and
- Earth Quake Loading.

These factors and their influence will be described in detail within Section 6.1.4. To assist the reader Figure 10 provides some key structural definitions and features.

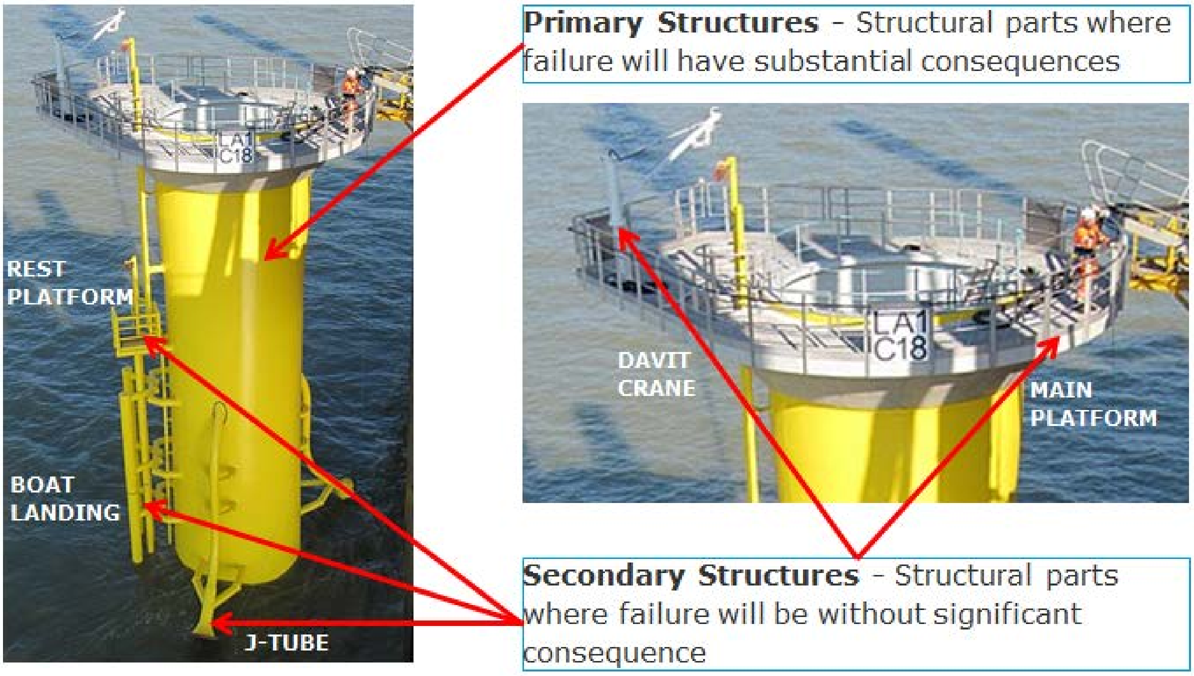


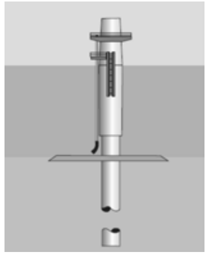
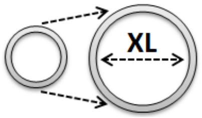
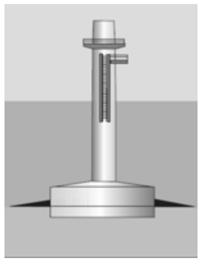
Figure 10: Key Structural Definitions.

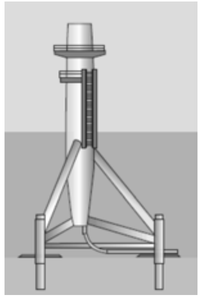
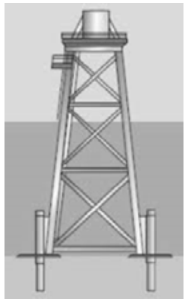
6.1.2 Fixed foundation types

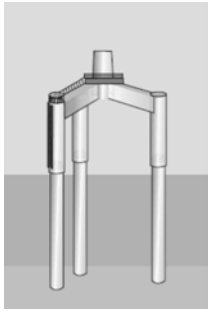
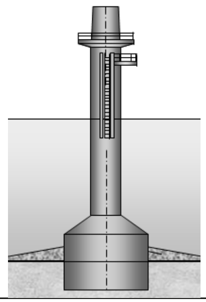
Table 12 summarises the salient features of fixed foundation technologies and their typical water depths, wind turbine (WTG) MW Class and soil conditions.

Further foundation types and variants have been considered and deployed (e.g. Floating and Multi-member) however this section focuses on common classes of foundation at the time of writing rather than novel variants. Given the time-line for offshore wind development in India it might be wise to consider further foundation types in future studies as research and development advances.

Table 12: Fixed Foundation Technology.

Technology	Typical Conditions			Construction	Advantages	Disadvantages
	Depth	WTG (MW)	Soil Type			
Monopile 	Up to 30 m	<4 MW	Wide range soil and rock (driving and drilling possible). Soft-soil: lateral high loading possible issue.	Consists of a single steel pile embedded into the seabed. Turbine tower connected to foundation via a transition piece or directly bolted to MP. Diameter <6 m and mass <650 tonnes.	▪ Low cost ▪ Design simplicity ▪ Rapid fabrication ▪ Installation flexibility ▪ Vast offshore deployment ▪ Levelling (grouted connection)	▪ Noise during piling ▪ Large hammer availability ▪ Heavy lift vessel ▪ WTG Frequency constraints (soft foundation) ▪ High lateral loading to soil ▪ High quality specialist fabrication required ▪ Thick steel plate required up to 100 mm
Monopile (XL) 	Up to 50 m (assumed)	4-8 MW	Range of soil and rock (driving and drilling possible – assuming large diameter drill locally available) Soft-soil: lateral high loading possible issue	Larger diameter 6-10 m for deeper water and larger MW Class WTGs. Mass 800-1000+ tonnes	▪ Reduced fabrication cost compared with Jacket ▪ Suited for automated production	▪ Heavy lift vessel ▪ New driving tech. required ▪ Limited in hard soil or rock ▪ High quality specialist fabrication required ▪ Thick steel plates required.
Gravity-based structure (GBS) 	Up to 40 m (assumed)	Various	Firm and flat sea-bed. Requires scour protection. Not suitable in soft soils or where liquefaction is a risk.	Constructed in yards or on barge and transported to site (barge or float out). Mass is increased by filling the structure with sand or rock ballast. Structure mass = 2000-3000 tonnes. Ballast = 1500-2500 tonnes	▪ Reduced Fatigue & Corrosion Sensitivity ▪ Uses concrete which is readily available and low cost ▪ No pilling required ▪ Avoids tensile forces between structure and seabed ▪ Well proven	▪ Very heavy – lifting/transport ▪ Slow fabrication ▪ High frequency (stiff) ▪ Requires extensive fabrication space ▪ Lack of experience in deep water ▪ May require sea-bed preparation ▪ Requires scour protection

Technology	Typical Conditions			Construction	Advantages	Disadvantages
	Depth	WTG (MW)	Soil Type			
Tripod 	20 to 40 m	4-6 MW	Wide range of soils (rock possible with drilling)	Central tubular member (dia. 5-7 m) with 3 offset braced piles – principle: extension of MP depth range with multi-piles. Piles can be pre-installed or post installed after tripod placement on seabed.	▪ Extends MP depth range ▪ No transition section ▪ Well proven ▪ Reduced welds compared with Jacket	▪ Mass & Cost typically > Jacket ▪ Critical central joint with high stresses (located in wave region) ▪ Design outside standard equations ▪ Large vessels are required ▪ Pile-tension problems ▪ Heavier than a steel jacket ▪ Limited ability to fabricate in sections ▪ Thick plate needed, and large welds, making automation difficult
Jacket 	Up to 50 m	4-8 MW	Wide range of soils (rock possible with drilling) Soft-soil: pile sway effects possible issue	Comprised of 3 or 4 legs connected by slender braces. Multiple fabricated (or Cast) "K" and "X" joints. Turbine tower connected by transition piece (different variants). Piles can be pre-installed or post installed after tripod placement on seabed.	▪ Deeper water and large MW WTG proven alternative ▪ Known from O&G ▪ Light mass for water depth ▪ Stiffness can be tuned by Transition Piece design ▪ Good resistance to overturning ▪ Thinner individual sections better suited to automation and mass fabrication than a tripod.	▪ Fabrication complexity, high number of welds ▪ Joints often require expensive castings ▪ Secondary Structure attachment ▪ High stiffness limitation in shallow water – WTG frequency constraints ▪ Pile tension loads

Technology	Typical Conditions			Construction	Advantages	Disadvantages
	Depth	WTG (MW)	Soil Type			
Tripile 	25 to 40 m	3-6 MW	Wide range of soils but not rock	Comprises of 3 foundation piles which extend and are grouted above sea-level. Piles are connected by a common transition piece.	▪ Proven – although limited use & patented ▪ Common transition piece for range of water depths – selling point: common fabrication ▪ Utilisations at connection reduced as above splash zone	▪ Complex tri-form transition fabrication ▪ Tight installation tolerances ▪ Extensive structure visible above sea level ▪ Secondary steelwork, anodes etc. need to be installed after piling ▪ Pile diameter larger than Jacket ▪ High fatigue moments at pile to transition joint. ▪ Large steel mass compare to jacket.
Pile Cap 	0 to 15 m	<4 MW	Soft soils to considerable depth	Common in China's shallow inter-tidal sites. Comprises 8-16 small diameter raking piles (driven to considerable depth). Concrete cap cast offshore using re-usable formwork.	▪ Suitable for soft soils to considerable depth ▪ Well know – but only proven in sheltered harbours ▪ Reduced welding ▪ Smaller hammer and vessel sizes	▪ Extensive offshore fabrication ▪ High wave loading, risk of wave run-up on pile-cap ▪ Shallow sites and small WTGs only ▪ Load transfer between cap and piles
Suction Caisson 	0 to 30 m (>30 m considered)	Various	Very Specific soil conditions Too soft = global stability problems Too hard = no seabed penetration	(1) Steel skirt caisson structure penetrates into seabed under self-weight/hydro-static pressure. (2) Water pumped out to create suction. (3) Ballast added post installation to aid stability	▪ Avoids piling ▪ Potential fast installation ▪ Potential lower mass ▪ Low underwater noise	▪ Limited application for WTGs ▪ Limited soil conditions ▪ No rocks or boulders ▪ Scour protection ▪ Highly specialist design and construction method

6.1.3 Best practice for foundation type selection and design (in Europe)

As stated selecting the "best" foundation type for an offshore wind project is a critical decision for both technical and commercial feasibility (e.g. cost reduction). Due to the critical nature of this decision a significant amount of engineering effort is employed during the early design stages to get this right. Not only must the foundation be matched to the site-specific conditions it must also be well paired with the specific wind turbine model. In fact for the majority of cases the geometric footprint and member sizes of steel offshore wind foundations are primarily driven by turbine specific factors; such as the turbine natural frequency window (determines footprint), extreme loading (determines pile embedment) and turbine fatigue loading (determines member wall thickness and diameter). Combining these turbine factors with the local geotechnical (seabed conditions), wave and current conditions there is no substitute for a site-specific foundation design and type selection.

This site-specific approach to design is now common place in European projects and a widely used approach is summarised in Figure 11. It is of course feasible to jump one or two of the early design stages (screening, concept design or FEED) but it can be proven both from offshore wind and offshore oil & gas that reducing the early stage effort will likely yield a higher risk and less optimised design (both technically and economically). In Europe by the end of 2014 it can be noted that approximately 79% [22] of installed foundations are monopiles, nevertheless these foundation choices are seldom a straight forward decision and the majority of projects would carefully study the site-specific conditions in conjunction with the specific wind turbine models from an early project stage. Monopile deployment at numerous sites in Europe appears cost effective with the recent turbine MW class and water depth combinations and where ground conditions allow for direct pile driving. Outside this envelope other foundation options such as jackets, tripods, gravity bases and others may become favourable. Even if monopiles are selected from an early project stage there still exist significant room for optimisation given the many monopile concept variants. For example, to mention only a few design variants, monopiles can be developed with or without transition pieces (section connecting turbine tower to monopile), with grouted connections or with bolted connections, with internal or external array cable routes. Jacket and other foundation types have their own set of important design variants. The large number of available foundation types and subsequent variants highlights the importance of a site-specific selection and progressive design cycle from an early project stage, see Figure 11.

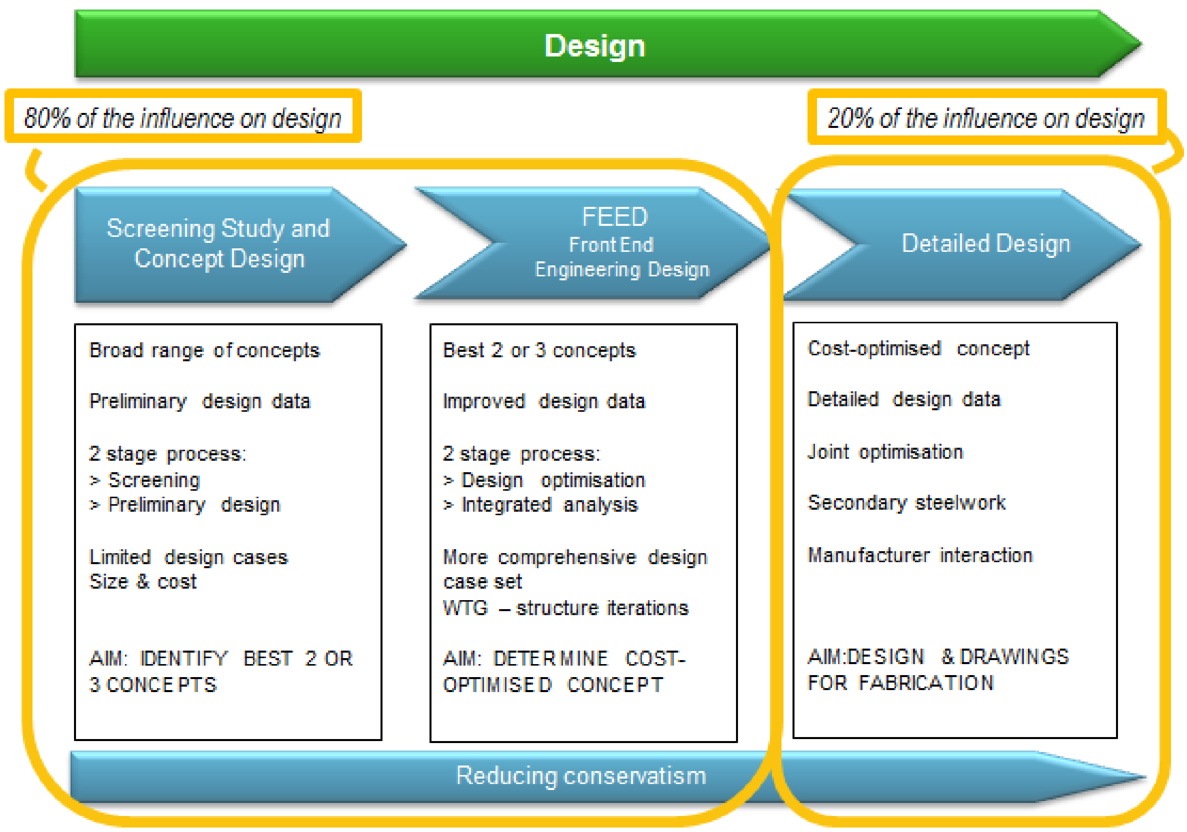


Figure 11: Progressive Offshore Wind Turbine Foundation Design Methodology.

The final part of this section describes the key steps for design and selection of foundation types and variants (illustrated in Figure 11). DNV GL considers this an example of best-practice currently undertaken in European projects. It is not to say each and every project follows this prescribed method but the overarching objective in all cases should be to provide a cost-optimised foundation solution and to mitigate fabrication, installation and operational risks through design.

Stage 1A: Screening Study – this type of study would typically be undertaken as a first step in a project's development or as part of a pre-feasibility study such as this. Various different foundation types would be screened at high level against available site-specific conditions and known project constraints (e.g. wind turbine MW Class, local vessel lift capability, and local fabrication capability). No structural analysis would be conducted; the study would be qualitative and based on experience and engineering judgement. The objective would be to disregard obvious unsuitable types and provide a short list of foundations types to be taken forward for further consideration (e.g. to Stage 1B Concept Design).

Stage 1B: Concept Design – this might also be referred to as "Pre-FEED" or "Concept Design" and would typically form part of a more detailed feasibility study. Concept design would provide an indication of foundation risks and costs. The bigger and more complex the site, the more choices there are that need to be considered and, where possible, eliminated. During concept design a site-specific design basis would be developed to include wind turbine concept loads and site-specific metocean conditions. Following this, design cases would be run for key foundation/WTG combinations, ground conditions and water depths. This analysis would be simplified using a shortened set of extreme and fatigue load cases. The objective might be to estimate the CapEx costs to ± 30% and identify key risks for each combination and identify for example the "best" 2-3 foundation types to take forward for further consideration (e.g. Stage 2 FEED).

Stage 2: Front End Engineering Design (FEED) – A full FEED study is a comprehensive concept engineering design study covering the key technical and commercial packages (e.g. foundation design, turbine selection, electrical system design, installation, etc.). The aim is to define the major contracts, identify, quantify and reduce project risk and overall project cost. For the foundations the focus of the FEED is to identify the "best" and cost-optimised foundation type and wind turbine model combination. As illustrated by Figure 12 there are a number of key interfaces and interconnections within an offshore wind project that will affect the selection and optimisation of foundations – a FEED study aims to provide a detailed understanding of the major factors. Typically the 2-3 foundation types from Stage 1 (combined with the key wind turbine models under negotiation) will be taken forward to FEED and subjected to more rigorous analysis. For example, more advanced load calculations would be conducted compared with Stage 1 and the bulk of the foundation optimisation might occur in this stage. These concept designs might target CapEx estimates within ± 15-20%. The site-specific design basis would be updated and informed by higher resolution wind, metocean and geotechnical data gained from high quality offshore wind/metocean measurement and seabed survey campaigns. The cost-optimised concept can help define contracts with the provision of functional requirements, technical specifications and in some cases the FEED design itself can be included within the invitation to tender (ITT) documentation.

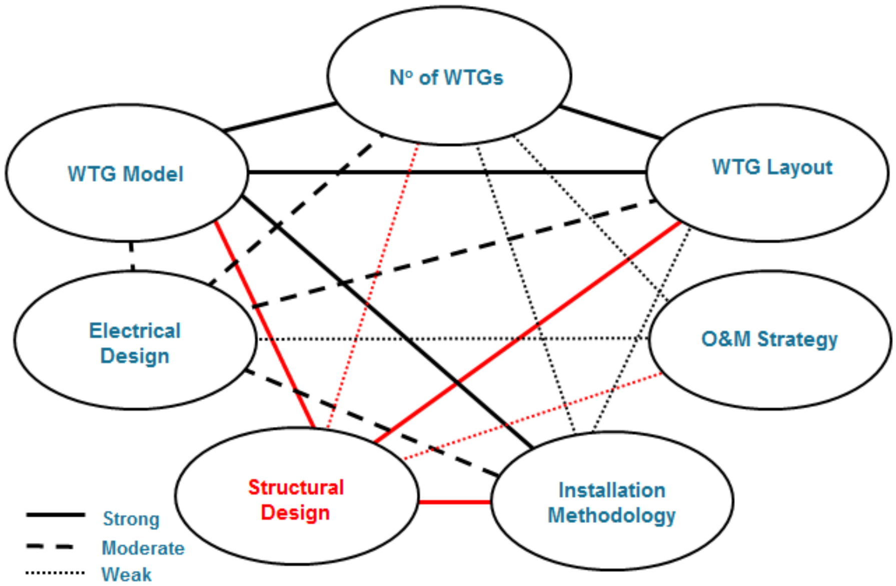


Figure 12: FEED - Interconnectivity between Engineering Design Elements.

Stage 3: Detailed Design – the objective of the final design stage is to provide a comprehensive foundation design for both primary and secondary structures that is both fit for fabrication and installation. Designs must comply with the employer's functional requirements and be suitable for each specific turbine location. Deliverables would include a comprehensive package of design basis, design briefs, design reports, primary steel drawings, secondary steel drawings, design risk register and structural models. It is critical at this stage that the design is developed in conjunction with both the fabrication and installation contractors. A common best-practice approach for identifying fabrication/installation design risks is to hold regular design risk assessment (DRA) workshops with the key interface representatives. Detailed design is a critical-pathway activity within the project schedule; until the design is approved fabrication cannot proceed. As a result of this the time schedule can be challenging and leave little room for design optimisation, hence the high value of starting this activity with a cost-optimised FEED design in hand. However this does not mean to say optimisation could not take place. For example during this process key load exchanges will be made between the wind turbine manufacturer and foundation designer and new advanced integrated loads analysis methods are being developed by the industry to help reduce the conservatism within wind turbine and metocean loading (see DNV GL's Project FORCE, [23]).

6.1.4 Key parameters for selection

In Europe foundation selection is primarily driven by cost, water depth and the dynamic features of the wind turbine. Generally within Europe, in particular around the coastline of the United Kingdom, seabed conditions are good and favourable for pile driving or drive-drill-drive installation. This aspect combined with the well-developed installation vessel and fabrication supply chain in Europe means foundation type selection might have less contributing influences than in a newly developing market such as India. It is anticipated that foundation selection in India will require very careful consideration of a number of additional parameters when compared with Europe. These may include; extreme loading from typhoons, additional dynamic loading from earthquakes, variable seabed conditions, high scour rates, limited vessel choice and fabrication experience.

This screening study will provide an informed subjective view and at high level try to understand the potential influences on foundation choice in each of the identified zones. The true magnitude of these influences for the majority of these selection parameters will only be understood with analysis from site-specific concept designs. This approach would be recommended for any future project specific studies (see Section 6.1.3).

The remainder of this section provides a brief summary of the key parameters that might drive foundation type and variant selection:

Cost - as stated foundation structures make up a considerable percentage of project CapEx and both stakeholders and policy makers are keen to reduce these costs. A key way of achieving this is to select the most cost efficient foundation and WTG combination. The most technically sound solution may not always be the most cost efficient and often technical compromises have to be made. A robust approach to cost estimation must be implemented when refining the selection. Offshore wind has been identified as too expensive in Europe and advances in cost reduction are critical. In response to this numerous cost reduction task forces and projects have been launched including XL monopiles, serial production of jackets and DNV GL's "Cost-reduction Manifesto" [24].

Water Depth – this parameter is a primary influence on both foundation type and cost. Increasing water depth means a longer lever arm increasing the overturning moment at the seabed. This requires a more robust and stiffer structure that inevitably influences the structural frequency factors described below. Increasing water depths will generally intensify metocean loading on the structure especially when combined with large diameter members. In shallow sites loads from breaking waves would require careful consideration.

Wind Turbine MW Class and Frequency Window effects – offshore wind turbines have a natural frequency window for structural design, this is a key driver for foundation type selection. The constraints of this nature frequency window for a three bladed turbine are illustrated by Figure 13. If the natural frequency of the turbine and foundation do not fall within this window dynamic amplification of the loads will occur. In the worst case this could mean structural failure or at best higher fatigue utilisations and a reduced structural life. The lower bound of the window is known as the "1P Frequency", the frequency associated with the once-per-revolution centrifugal force resulting from a slightly off-centre rotor mass distribution. The upper bound is known as the "3P Frequency" (3 Bladed Turbine), frequency associated with the blades blocking wind loading on the tower, occurs three times per revolution. Most wind turbines are variable speed and manufactures apply safety margins, hence the actual frequency window is turbine specific, some are wide and some are narrow. It is this frequency parameter that makes designing monopiles for deeper water challenging due to their inherent flexibility and also the application of jackets in shallow water due to their high inherent stiffness. For example "forcing" a jacket into shallow waters will likely result in a very narrow footprint and heavily utilised joints and members. The end result potentially being an un-optimised and costly structure. If the WTG manufacturer is engaged early in the design process it may be possible to adjust the target frequency window. This has a very marginal effect on the power yield but can be very beneficial for the foundation.

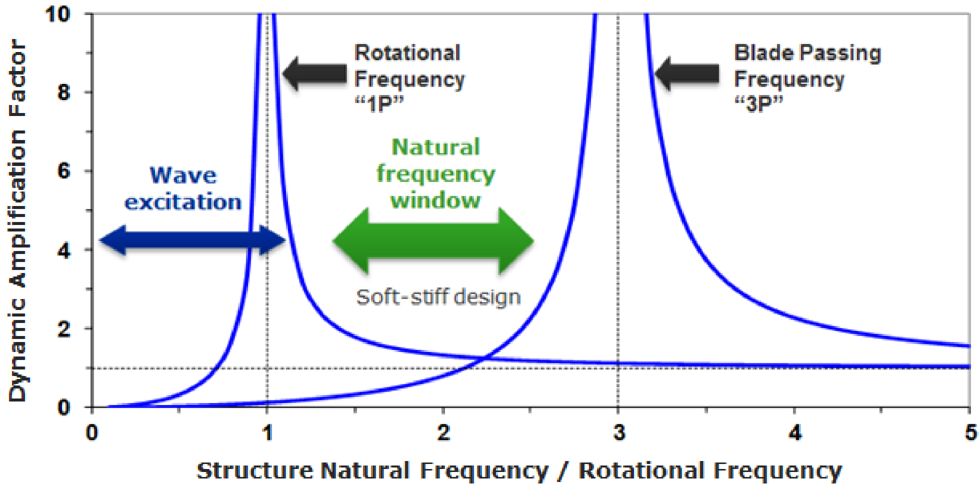


Figure 13: Natural Frequency Window and Dynamic Amplification.

Ground Conditions – when selecting fixed offshore wind foundations a good understanding of the ground characteristics below the seabed is critical. At feasibility stage it is possible to use broad assumptions and data can be obtained from desk studies. Later design stages require comprehensive geophysical and geotechnical survey campaigns. Geohazards such as igneous intrusions, boulders and anthropogenic obstructions, mobile bedforms, shallow gas, geological faults and liquefiable soils, mud volcanos, sea bed slopes all influence site selection, site layout and foundation selection to some extent.

In general geohazards will influence the site selection and layout, as these may severely limit the development feasibility. Geotechnical extremes (very hard or soft ground) pose design challenges and may preclude some foundation choices either technically or economically. For example very soft unconsolidated soils (very young soils typically found in areas of high sedimentation such as the large deltas in Asia) often result in limited lateral support and subsequent larger foundation embedment and mass. Gravity based structures are also unlikely to be suitable in this situation due to the need for a very wide base and issues with potential long term settlement. Multi-pile solutions could be more beneficial in softer soils. On the other extreme the presence of hard rock will require piles to be drilled (or a combination of "drive-drill-drive") which will increase installation time and cost. Installation considerations such as pile drivability and drilling risk studies are an important aspect of early stage design.

Local Installation Vessel Availability – the lifting capability of offshore installation vessels available to the local market at a realistic cost must be taken into consideration during the early design stages. For a 6 MW WTG in 30 m of water monopile fabrication costs are lower than a jacket but the monopile lift weight (1200-1500 tonne) may be double that of an equivalent jacket (600-700 tonne) [25]. This clearly has a big impact on foundation type selection as all foundation solutions must be installable.

Local Fabrication Capability – the local fabrication supply chain can influence foundation choice, for example regions with a strong oil and gas industry may possess good capability for jacket fabrication. Monopiles require thick plate large diameter rolling experience. While monopiles are well suited to serial production (as practiced in Europe) they require high accuracy welding with a comprehensive Quality Assurance process in place. Substandard monopile fabrication can cause major delays and expensive remediation programmes. The location of the fabrication facility with respect to the wind turbine manufacture and offshore wind farm will also affect transportation logistics and cost.

Extreme Wind Speeds (Typhoons) – for regions that have a high risk and history of typhoons or tropical cyclones it is critical that all extreme wind speed data and extreme load sets contain typhoon effects. Typhoon wind loading combines high speeds, fast changing and twisted wind shear profiles and high turbulence making designs challenging. A significant amount of research and development focused on wind turbines has now been conducted, in particular reference can be made to the DNV GL Technical Note "Certification of Wind Turbines for Tropical Cyclone Conditions" [26]. When developing offshore wind farms typhoons will influence the following; wind resource assessment methods, wind turbine selection (IEC Class), extreme load calculation, insurance and risk and safety mitigation during both construction and operation. With regards to foundation design, higher typhoon extreme loads may for example require longer pile embedment and heavier extreme load utilisations in joints and members. In some structural areas typhoon extreme loading could become the driving load case for member and joint geometry.

Earthquake Loading – Earthquake loading for wind turbines and structures is documented within the following design standards: DNV-OS-J101 (S 3.8.1; S 4.5.8) [27], IEC 61400-1 [28](S 11.6, Annex C) and the GL Guidelines for the Certification of Offshore Wind Turbines [29](S 4.2.4.7; S 4.3.7; S 4.4.2.6; T 4.4.1; S 4.4.6). The GL Guideline recommends that if horizontal ground acceleration exceed 0.05g m/s^2 (g being gravitational acceleration) then earthquake analysis is required in structural design. Typically local building codes or measured data provide sources of information for defining the accelerations and frequencies which define the earthquake. The key hazards to foundations from earthquakes are as follows: additional dynamic loading, soil liquefaction, seismic settlement, lateral soil spreading, enlarged waves (tsunami), soil boil, cyclic degradation of soil parameters and plastic deformation of the soil. Liquefaction is particularly a risk during an earthquake event within areas of loose sand and silt or very soft high water content clay sediment. Earthquake loading in both areas of liquefaction and areas of non-liquefaction can cause buckling of piled structures or overturning of gravity bases. These areas are also likely to provide poor lateral resistance for piles. It may be feasible to design piled foundations in areas of soft sediment, assuming the piles could be founded in suitable material or the underlying bedrock.

6.1.5 Gujarat geotechnical conditions

During the preliminary site selection (see Section 4.3) sediment thickness was selected as a parameter (though with a small weighting) to evaluate the feasibility of the site. This was conducted based on data from the NOAA which maps the sediment thickness based on the acoustic basement. This is the depth/strata of the earth below which other strata cannot be imaged with seismic data. Locally, acoustic basement could be equivalent to geologic basement, magnetic basement, or even some other surface. It has been reported that locally the acoustic basement of offshore sediments is the depth of the Pleistocene consolidated sediments, above which are early Holocene and contemporary/recent clays. This thickness was then used to determine the most suitable areas for development with the thicker areas of sediment being considered the most suitable.

This approach makes the assumptions that;

- The acoustic basement equates to the sediment thickness;
- That foundation costs increase with less sediment which is based on European experience that the additional drilling required when piled foundations are used, and additional costs are associated with vessel and infrastructure improvements with GBS.

The assumptions are indicative and general, hence why a small weighting was assigned for this aspect of the pre-feasibility study.

To assess the engineering suitability of the ground conditions for offshore wind farm foundations in the selected zones the following method was adopted:

1. Conduct literature review and establish geological history;
2. Identify potential geological hazards and geotechnical conditions;
3. Evaluate the potential impact of the geohazards and geotechnical condition against the 3 primary offshore wind turbine foundation options (monopile, jacket piles and gravity based structures).

It should be noted that due to the level of data available there is a limit to the amount of detail and the conclusions that can be drawn from such an exercise;

- The summary of geohazards should be considered indicative and not exhaustive;
- No site specific geotechnical profiles or properties should be drawn, hence site specific design is not possible at this stage;
- The location of some geological features is not possible to predict, however within large zones it is possible to microsite the WTGs around these, hence they are considered that they can be accommodated in design.

Offshore geological maps were not available when preparing this literature review, hence referenced sources are the only sources of information.

6.1.5.1 Offshore geotechnical conditions

Introduction

Gujarat is situated in north-west India on the margin of the Indian craton (a relatively stable area of a continent). It is bound in the north-east by the Aravalli Mountain range to the north and was formed by the pre sub-continental plate collision with the mainland Eurasian plate circa 200 million years ago. The plate boundary is still currently active with the Indian plate moving at approximately 2 cm a year towards the Eurasian plate and past the Arabian plate which forms a strike slip boundary. The main land mass of Gujarat is part of the large igneous Deccan Trap which is composed of volcanic extrusions of rock formed in the Mesozoic to Cenzoic boundary 100 million years ago. Other rock outcrops in the region are from the Jurassic to late cretatous era (circa 150 million years before present (mybp)) of which the sandstones and silt stones have the potential to bear hydro carbons.

Gulf of Cambay (Areas "A"-"F")

The Gulf of Cambay is located in the south western part of the State of Gujarat, and is adjacent to the main Arabian Sea area. It covers over 3,000 km^2 with several rivers, including the Narmada, Tapti, Sabarmathi and Mahi, draining into it.

The rivers have resulted in the formation of several long linear sandy shoals which are formed upon the surrounding clayey formations. Comparison of historical mapping indicates that the bathymetry is very dynamic with the growth of bars, levees, mud flats and islands, in addition to the movement of the sandy shoals.

The area is tectonically active and has three major faults [30], designated as the Cambay graben fault trending in a N-S direction, west coast fault along NNW-SSE direction on the east coast and the approximately EW-trending Narmada geofracture.

A survey by the National Institute of Ocean Technology (India) has indicated that the geology of the area is comprised of recent sand and clay deposits, permeated by paleo-channels, with both of these formations being relatively shallow and followed by a thin layer of conglomerate with the underlying bedrock being a sandstone.

Arabian Sea (Areas "G" and "H")

The study area that is not part of the Gulf of Cambay is the eastern edge of the Arabian Sea. The western shelf of India (and eastern part of the Arabian Sea) is covered by three different types of sediment. From the coastline to a depth of 5-10 m are coastal sand deposits; these are succeeded further out by silts and clays to 50-60 m. Both of these deposits are formed by weathering and erosion of coastal rocks. Beyond this limit is coarse calcareous marine Holocene sand formed by depositional and sedimentary processes when the sea level was 60-90 m lower. These have lithified and cemented and can be considered soft to hard rock. In the southern area these are calcareous sandstones, and towards the North and North West various limestones are dominant.

Numerous historic and neo-faulting features are present and are known to be active

6.1.5.2 Ground earthquake risk

The Gujarat region is located near to two plate boundaries and hence has a high potential for seismic activity as described in the introduction above. In general the Gujarat region can be divided into three different areas with varying earthquake hazards levels ranging from moderate to high. Figure 14 provides an overview of the Gujarat earthquake risk zones [31].

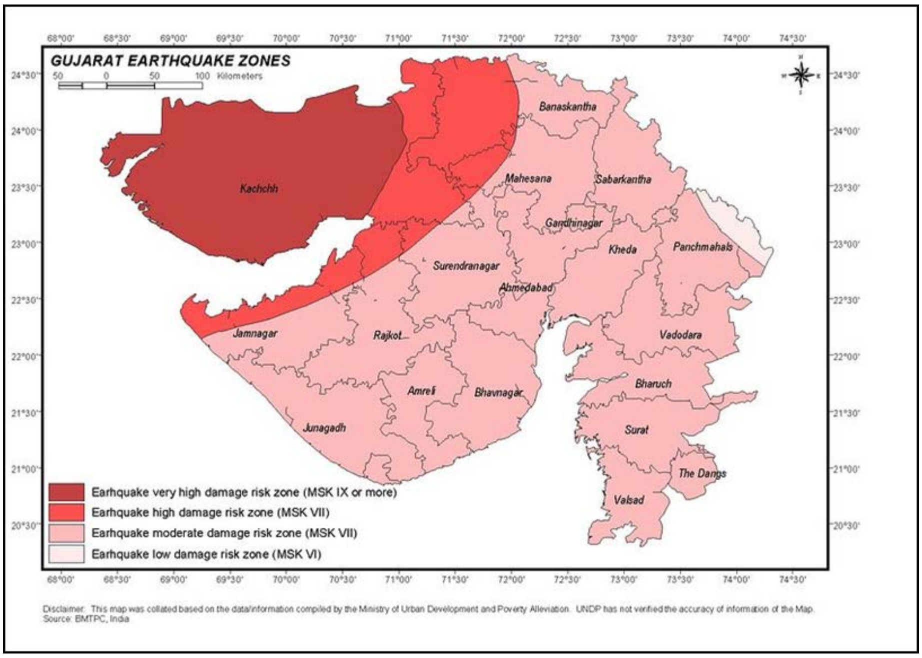


Figure 14: Earthquake Hazard Risk Zonation: Seismo-techtonic features of Gujarat.
Source: **[32]**

These earthquakes cause ground shaking which impacts the ground-pile-structure in a number of ways;

- Kinematic interaction due to the forced displacement of the ground surface [33];
- Inertial interaction due to the inertial forces from superstructures being transferred to the pile foundation [33];
- Physical interaction (e.g. in cohesive soil gaps at the pile-soil interface during earth quake can be opened resulting in a reduction of soil-pile lateral stiffness. [34];
- Radiation damping - piles vibrate at higher frequency than soil, but 'soil-pile' contact forces the soil to vibrate at these high frequencies, resulting in the transmission of high frequency energy away from the pile into the surrounding soil [34].

When considering how an earthquake will impact the foundations the first step is to assess the liquefaction potential of the soil. Liquefaction is a phenomenon which occurs when saturated sediments (typically sand and silts) temporarily loose strength and act as a fluid. Table 13 summarises impacts that should be considered when evaluating the earthquake in liquefiable and non-liquefiable soil. In addition the loading for the earthquake must be considered in combination with wind and wave loads for a number of load cases which are dealt with in international design codes.

Table 13: Ground Earthquakes Risk

Non liquefaction induced phenomena	Liquefaction induced phenomena
Bending Failure (or excessive displacements) resulting from loss of lateral support due to strain softening of cohesive soil combined with high inertial forces (failure near the pile head).	**Sand-boil**: when a non-liquefied clay layer overlay a liquefied sand layer. The earth quake causes the clay layer to crack. Liquefied sand can occur through the cracks forming soil-boils.
Failure associated with **excessive bending** moment at the interface between soft and stiff soil layers.	**Bending failure:** due to high inertial forces. Maximum bending moment and pile deflected shape are strongly affected by first set of layers.
Pile permanent vertical displacement due to loss in bearing capacity associated with 'rocking mode' induced by superstructure inertial force [34].	**Pile settlement:** due to loose in bearing capacity associated with rocking mode induced by superstructure inertial force [34].
	Lateral Spread of soil: liquefied soil, with gentle slope, flow along the interface between liquefied and non-liquefied layers causing lateral compression on the pile. The pile can be damaged at both top and bottom.
	Buckling instability: Currently, piles in liquefiable soils are designed as beams to avoid bending failure arising from lateral inertial and kinematic (lateral spreading) loads. Recent research suggests that part of the pile in liquefiable soils needs to be treated as unsupported structural columns to avoid buckling instability [35].

Non liquefaction induced phenomena	Liquefaction induced phenomena
	The pile can buckle and push the soil. This instability depends on the slenderness ratio of the pile exceeding a critical value in the liquefiable region. Once the surrounding soil has its effective stresses eliminated by an earthquake, a susceptible pile starts to buckle in the direction of least elastic stiffness. If the soil around the pile remains liquefied for long enough, the pile will suffer gross deformations and the superstructure will either tilt or deform' [36].

6.1.5.3 Geotechnical influences on foundations

This review has highlighted a number of ground risks that must be considered when evaluating the foundations in Gujarat;

- Changes in Bathymetry in the Gulf of Cambay;
- Loose liquefiable deposits combined with earthquake loading;
- Shallow gas;
- Soft/loose young deposits near surface; and
- Potentially shallow depth to rock head.

Without site specific data it is not possible to evaluate the presence / absence of these features (or others) at the proposed locations. However, to enable the comparative pre-feasibility exercise it shall be assumed that the soils deposits are thick enough to permit piled foundations (or that drilling would be performed if not) and that WTGs are microsited around local geohazard features.

6.1.5.4 Geological features and foundation risks

Table 14 summarises the impact that a number of the identified geological features could have on the three main types of offshore wind farm foundation.

Table 14: Impact of selected geological features on the 3 main types of offshore wind farm foundation.

Geological Feature	Monopiles	Jacket Piles	Gravity-based structure (GBS)
Seismically active and loose liquefiable deposits at surface	• Piles may need to penetrate to "base layer" to ensure stability during earthquake • Piles must accommodate loading	• Piles may need to penetrate to "base layer" to ensure stability during earthquake • Pile relative displacements during loading must be considered • Piles must accommodate loading	• GBS may not be suitable due to sinking in liquefiable soils • GBS must accommodate loading
	2	2	1

Geological Feature	Monopiles	Jacket Piles	Gravity-based structure (GBS)
Seismically active and Non liquefiable deposits at surface	• Piles must accommodate loading • If soil below non liquefiable deposits can liquefy "sand boil" must be considered	• Piles must accommodate loading • If soil below non liquefiable deposits can liquefy "sand boil" must be considered	• GBS must accommodate loading • If soil below non liquefiable deposits can liquefy "sand boil" must be considered
	3	3	3
Shallow (<5m) Depth to rock head	• Piles may require drilling (either drive-drill-drive, predrilling pilot hole, or drill and grouting)	• Piles may require drilling (either drive-drill-drive, predrilling pilot hole, or drill and grouting)	N/A
	4	4	4
Young soft / Loose deposits	• High scour potential • Negative skin friction potential • Compressibility • Longer piles	• High scour potential • Negative skin friction potential • Compressibility • Longer piles	• High scour potential • Compressibility and excessive deformations
	3	3	2
Horst and Graben fault systems	• Significant changes in lateral variability • Localised soft areas • Landslides associated with neo tectonic activity	• Significant changes in lateral variability • Localised soft areas • Landslides associated with neo tectonic activity	• Significant changes in lateral variability • Localised soft areas • Landslides associated with neo tectonic activity
	3	3	3
Shallow gas;	• Can be a HSE risk during construction • Soils with dissolved gas content can have unpredictable strength	• Can be a HSE risk during construction • Soils with dissolved gas content can have unpredictable strength	• Can be a HSE risk during construction • Soils with dissolved gas content can have unpredictable strength
	3	3	3
Changes in Bathymetry due to hydro sedimentary processes	• Changes in the sea bed must be accounted for in pile design • Changes in the sea bed must be accounted for in cable interface design	• Changes in the sea bed must be accounted for in pile design • Changes in the sea bed must be accounted for in cable interface design	• Changes in the sea bed must be accounted for in GBS design • Changes in the sea bed must be accounted for in cable interface design
	2	2	2

1 – Likely to be limiting
2 – Must be considered in design (including micro siting), potentially limiting
3 – Must be considered in design (including micro siting), but can probably be accommodated
4 – Must be considered but unlikely to be technically limiting

6.1.5.5 Summary and next steps for Gujarat

As discussed there are a number of significant limitations with the current review. To further evaluate the feasibility of the zone development the steps outlined in Figure 15 would be taken in the development of a typical offshore wind project.

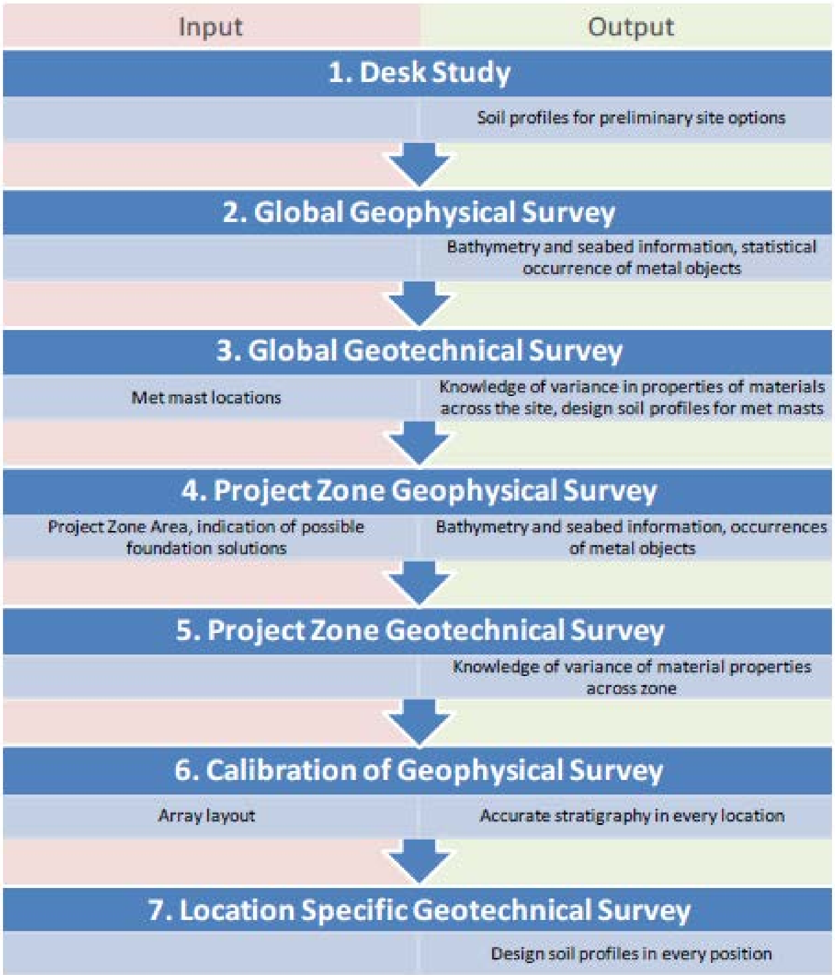


Figure 15: Typical steps for evaluating the ground conditions for an offshore wind farm.

6.1.6 Other Gujarat specific conditions influencing foundation choice

6.1.6.1 Wind turbine MW class

Wind turbine classes of 4 MW and 6 MW are considered within this screening study, see Section 5.

6.1.6.2 Water depth

Water depths within the selected Gujarat zones range from 15 to 43 m below LAT. This is within the acceptable range for market ready foundation concepts.

6.1.6.3 Tidal currents

Given its estuarine location the Gulf of Khambhat exhibits high tidal flows, it is hence anticipated that foundation installation in at least Zone F would be challenging. Reported spring peak flows in this area are between 4 and 7 knots when considering local tides (with reference to tidal diamonds and local port operators). It is also likely that many areas of Gujarat are susceptible to high scour rates; this would require foundations to be either designed for large scour loss around the piles or well protected with a suitable armouring.

It is generally considered challenging and limiting for jack-up vessels to install in tidal flows (and often stated in their standard specification sheets) over approximately 4 knots because it would be beyond their survivability limits. However, on a site specific basis, it may be possible to agree on acceptable scenarios; in this case very careful flow interaction analysis must be conducted for safe operation on a case by case basis. The biggest issue, as found within the European tidal stream industry, is vortex induced vibration (VIV) which is induced by the global sway of the vessel at low frequencies. Lattice legged jack-ups would help minimise this effect by increasing the vortex shedding frequency effect, but in this the lattice leg members themselves can become susceptible to VIV. Every vessel/foundation combination has different mass, stiffness and damping characteristics, and frequencies are dependent on the level of leg penetration and soil stiffness (if not on rock). For tidal stream energy sites the sea beds are generally rocky so scour is not an issue; but where scour can occur under and around the legs it is likely to be the dominant factor in safe operations.

6.1.6.4 Typhoons (WTG IEC class and extreme loads)

As part of the zone selection study typhoon (or cyclone) track data was considered from 1946 to 2007 (see Section 4.3). Only the “cyclone risk” areas were identified with a ranking of highest to lowest density of cyclones measured. Extreme wind speed influences should be investigated as part of a further detailed study. Hence it is not possible at this stage to predict the influence of typhoons on extreme structural loading. The highest cyclone density highlighted in Figure 4 appears to be in the northwest coast of Gujarat. The identified development zones are located away from the high density regions, however as stated the magnitude of extreme wind speeds requires further investigation.

6.1.6.5 Earthquakes

The State of Gujarat has earthquake hazards of different levels from moderate to high. In the Seismic zoning map of India [37], the Kutch region (about 300 km x 300 km) is categorised as Zone 5, where earthquakes of magnitude 8 on Richter scale can be expected. A stretch of about 60-70 km width around this zone covering areas of North Saurashtra and areas bordering eastern part of Kutch is categorised as Zone 4, where earthquakes of intensity 8 on Richter scale can be expected mainly due to earthquakes in Kachchh and the North Kathiawar fault in Northern Saurashtra. Areas in rest of Gujarat are categorised as Zone 3 where earth quakes of intensity 7 on Richter scale can be expected due to moderate local earth quakes or strong earth quakes in the Kutch region.

During the preliminary zone selection (see Section 4.5) areas with a seismic intensity zone of 5 were excluded from the study domain.

The selected zones are all located off the coast of the Saurashtra region, in a recent study [38] the surface peak ground accelerations have been estimated at 0.05 g to 0.20 g m/s^2. It is hence anticipated that all foundation designs within the Gujarat region will require seismic analysis, liquefaction investigations and analysis of other earth quake hazards. This should be investigated further within the full feasibility study.

6.1.6.6 Installation vessel availability

It is anticipated that the use of local installation vessels should be possible however adaption during mobilisation might be required e.g. to accommodate larger capacity cranes. It is locally understood that if larger vessels are required it may be possible to obtain these from Singapore or Malaysia, particularly of the Shearleg class.

Typically for steel wind turbine structures the monopile type would require the heaviest single lift. A monopile installation method using a Shearleg vessel to upend and place the monopile in the pile guides of a pre-positioned piling jack up can be carried out. Vessels capable of this construction methodology are believed to exist locally. As regards to larger jack-ups, several of suitable sizes are known to exist in the Middle East, which is relatively close to the Gujarat region.

At present, the number of vessels available, their specifications, and ownership remain unknown, and this has been identified as a future area of study for the FOWIND Infrastructure studies.

6.1.6.7 Local fabrication capability

In order to assess the requirements for marshalling facilities in ports, it is also necessary to have an awareness of the likely foundation and turbine manufacturer's locations, and whether it would be economic for installation vessels to operate directly between the manufacturer and the offshore wind farm site. If not an intermediate marshalling port might be prudent. Due to this fact during the recent FOWIND ports visit local fabrication capability was assessed to some extent.

Subject to suitable quality assurance, traceability and supply chain development it is currently considered that local fabrication of jackets, monopiles and offshore substation structures should be possible within India. This will be subject to further investigation in the FOWIND Infrastructure studies.

6.1.7 Foundation type screening – Gujarat

6.1.7.1 Methodology and assumptions

Methodology:

This section presents the results of the screening study in the form of a selection matrix using a simplified "Traffic Light" rating system; see Table 15 and Table 16.

Table 15: Screening Study "Traffic Light" Rating System.

Red	Foundation type not considered suitable
Orange	Foundation type somewhat suitable (with supply chain development or further analysis)
Green	Foundation type considered suitable (recommended for future concept analysis)

Using a qualitative approach based on DNV GL's experience from European and offshore wind markets in Asia a rating was developed for each zone and foundation type under consideration. It must be noted that the rating is not based on any numerical analysis and hence interpretation of the results and conclusions drawn must be treated with due caution. To gain a better understanding of foundation type suitability for the site-specific conditions DNV GL would advocate concept design studies in future project specific studies.

The following qualitative factors are considered within this screening study:

- Wind turbine MW Class (4 and 6 MW) – high level loading and structural dynamic effects; and
- Zone water depth.

In addition the following assumptions have been made:

Assumptions:

Vessels – it is assumed vessel availability will not constrain foundation masses up to 1000 tonnes. If the foundation is likely to exceed this mass the foundation type will be de-rated from green to orange and duly noted. XL monopiles are qualitatively considered to exceed 1500 tonnes when deployed with a 6 MW turbine in water depths greater than approximately 30 m (assumption based on DNV GL's experience, note site-specific factors would influence this).

Fabrication – it is assumed given the timeline for project development that India would possess the indigenous capability to fabricate the majority of mentioned foundation types; including gravity bases. However, XL monopiles are anticipated to need larger and specialist fabrication equipment and will hence be de-rated from green to orange.

Gravity Based Structures (GBS) – it seems likely given the anticipated ground condition variability and highlighted geohazards that GBSs might be challenging to develop in India especially without the availability of detailed site-specific ground conditions. Hence until further data is available GBS foundations will be de-rated from green to orange.

Suction Cassion Foundations – while there has been significant development with this foundation type for the support of wind turbines in Europe and China it is currently not considered proven or mature. Also, given the potential variability of ground conditions within Gujarat this foundation type, where relevant, has been de-rated from green to orange.

Tidal Flows – zones with extremely high tidal flows are considered challenging for installation. These recognised zones are hence de-rated from green to orange.

Other Assumptions – other assumptions used to compile the selection matrix can be found in Section 6.1.2 and geotechnical Section 6.1.5.3.

6.1.7.2 Screening matrix

Table 16: Foundation Screening Matrix.

ZONE	WTG (MW)	Water Depth (mLAT)	FOUNDATION TYPE RATING								Comments
			Monopile	XL Monopile	Gravity Base (GBS)	Tripod	Jacket	Tripile	Pile Cap	Suction Cassion	
A	4	-24	G	R	O	G	O	O	R	O	//
A	6	-24	R	O	O	G	G	O	R	O	XL monopile should be investigated but likely heavy lift
B	4	-17	G	R	O	O	O	R	O	O	//
B	6	-17	O	O	O	G	O	O	O	O	Standard MP with increase wall thickness perhaps possible
C	4	-28	G	R	O	G	O	O	R	O	//
C	6	-28	R	O	O	G	G	O	R	O	XL monopile should be investigated but likely heavy lift
D	4	-22	G	R	O	G	O	O	R	O	//
D	6	-22	O	O	O	G	G	O	R	O	Standard MP with increase wall thickness perhaps possible
E	4	-26	G	R	O	G	O	O	R	O	//
E	6	-26	R	O	O	G	G	O	R	O	XL monopile should be investigated but likely heavy lift
F	4	-15	O	R	O	O	R	R	O	O	Reported high tidal flows – challenging installation
F	6	-15	O	O	O	O	O	O	O	O	Reported high tidal flows – challenging installation
G	4	-42	R	O	R	O	G	O	R	R	Water depth limiting foundation choice
G	6	-42	R	R	R	O	G	R	R	R	Water depth limiting foundation choice
H	4	-43	R	O	R	O	G	O	R	R	Water depth limiting foundation choice
H	6	-43	R	R	R	O	G	R	R	R	Water depth limiting foundation choice

6.1.7.3 Recommendations and next steps

As can be seen from the screening matrix Table 16 and based on the input data available for Gujarat it seems monopile, jacket and tripod foundations would be likely choices to take forward for the next stage of investigation. If the local fabrication supply chain permits, there is likely merit in the detailed consideration of XL monopiles. In Europe these structures are already being widely used as a way to reduce foundation CapEx. To date the metocean and ground related data are not of sufficient resolution to confirm these choices and exclude other types with significant certainty, hence the following "next steps" are recommended:

- Gathering of more detailed zone specific extreme wind, metocean, earthquake and ground data;
- Conduct further ground desk study based on offshore geological maps and available boreholes and establish initial soil profiles for concept design and investigate preliminary scour risk;
- During the full feasibility study update screening study to consider higher resolution zone specific data and update conclusions; and a
- High level concept design study: concept foundation designs for the preferred foundation types and wind turbine MW class combinations in the most suitable and likely initial development zones. With the aim of understanding technical and commercial factors.

6.2 High level wind farm electrical concept considerations

6.2.1 Introduction

In order to transmit power from the offshore wind farm to the onshore grid system a dedicated electrical infrastructure is required. This electrical infrastructure typically constitutes about 20% of the project capital expenditure (CapEx).

This section discusses the typical electrical infrastructure and the high level wind farm electrical requirements for the transmission of power from an offshore wind farm to the nearest relevant grid substation.

6.2.2 Electrical grid infrastructure components

Some of the major components of the electrical grid infrastructure of a typical offshore wind power project are discussed below:

- **Subsea Array Cabling**: Subsea array cables are submarine cables which operate at 'medium voltage' levels – typically 33 kV - and connect the power produced at each wind turbine to the offshore substation. Here the power is collected and transformed to a higher transmission voltage level for transmission to shore. In cases where no offshore substation is used, the final cable section from the closest turbine on each array 'string' will stretch to the shore line interface, where either a beach transition cable joint pit or an onshore substation will be located.

- **Offshore Substation**: The offshore substation collects power from the wind farm via several medium voltage arrays and transforms it to a higher transmission voltage for export to the onshore substation via subsea export cables. Offshore substations are complex and expensive structures and their electrical components typically include grid transformers, medium voltage circuit breakers, transmission voltage switchgear, protection and control equipment including relays and battery systems, auxiliary transformers for supply of low voltage (LV power) on board, diesel generator sets for providing back up LV power supplies and various LV power and lighting equipment. The offshore substation may also contain reactive power compensation equipment. Typically an offshore substation consists of two key parts, a topside and substructure. A "topside" structure houses the electrical and safety equipment and is usually pre-assembled onshore. The topside will be located and founded on a pre-installed substructure, such as a jacket or monopile.

- **Converter platform:** The offshore transmission platform is used to collect power from one or more offshore substations via high voltage alternating current (HVAC) subsea cables and rectifies it from HVAC to high voltage direct current (HVDC). The power is then exported via HVDC cables to shore where it is inverted from HVDC back to HVAC at an onshore converter station in order to transmit the power to the onshore grid system. Offshore converter platforms are typically considered larger and more complex than offshore substations. Due to this high complexity the HVDC industry is characterised by only a few big players such as Siemens and ABB. The common design consists of a steel substructure, such as a jacket, and a topside as widely used in the oil and gas industry in the Middle East. Nowadays, alternative design solutions like semi-submersible structure are also being deployed (e.g. ABB DolWin 2, Germany).

- **Subsea Export Cabling**: Subsea export cables are submarine transmission cables which connect the power collected at the offshore substation back to the shore line interface, where either a beach transition cable joint pit or an onshore substation will be located. Depending on the capacity of the project and the voltage of the connection, there may only be one export cable connecting the offshore substation to the shore; therefore correct specification and installation of the cable is critical to minimise the probability of cable faults during operation. Submarine cable failures are generally difficult to locate and expensive to repair leading to significant losses of revenue.

- **Onshore Cabling**: Onshore cables may be used in cases where the onshore substation which connects the project to the grid is not located at the shoreline interface, which is often the case. The cabling generally connects at a transition point where it is jointed to the relevant submarine cable (either high voltage export or medium voltage array cable depending on the electrical system). The onshore cabling is of a similar specification to the submarine cable, but usually has aluminium rather than copper conductors which are preferred for cost reasons and require less water blocking measures such as lead sheathing.

- **Onshore Substation**: The onshore substation transfers power received from the offshore substation (or directly from the wind farm in the case of smaller close to shore projects) to the grid at a grid voltage or to the nearest load centre at required voltage. The onshore substation typically contains high voltage switchgear, control and protection equipment and may also contain reactive power compensation equipment and/or harmonic filtration equipment.

6.2.3 Offshore power transmission

Transmission of electricity from the offshore wind farm has to date been achieved by either alternating current (AC) or direct current (DC) transmission.

For wind farms which are within 50 km of the shoreline, an AC connection offers the most reliable, least risky and generally least costly option for connection. These AC configurations are divided into two different voltage levels: high voltage alternating current (HVAC) and medium voltage alternating current (MVAC).

HVAC transmission systems require an offshore substation with a transformer to connect the medium voltage inter array grid to the high voltage transmission system. Figure 16 presents a typical transmission network of an offshore wind power project which incorporates an offshore substation. The power generated by the offshore wind turbines is transmitted to the offshore substation via subsea ‘array’ cables and then to the onshore substation via one or more subsea ‘export’ cables.

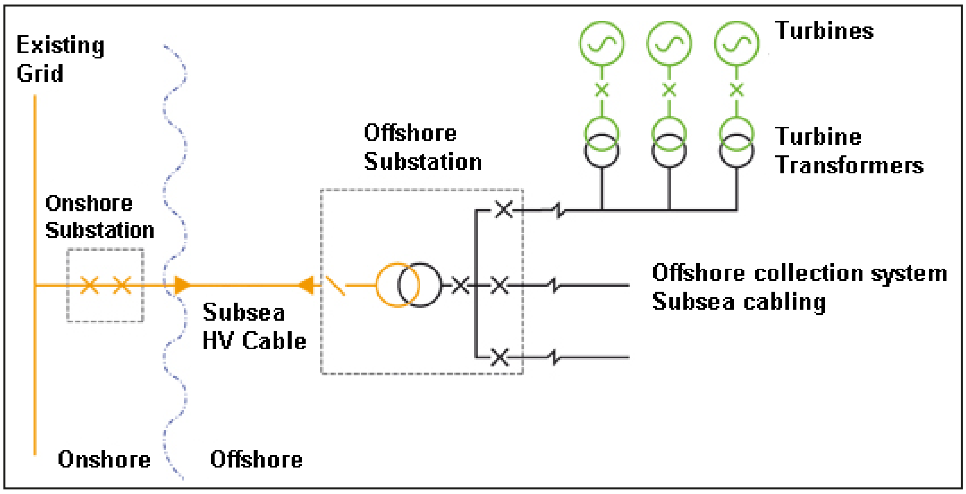


Figure 16: Offshore Wind Farm Transmission Overview. Source: **[39]**

HVAC transmission is the more commonly used method and generally uses similar electrical designs and transmission voltages to those seen on the majority of onshore national electrical transmission grids. HVAC is the primary connection method considered for offshore wind projects as it uses more widely available technology compared to HVDC and is a significantly less expensive connection solution.

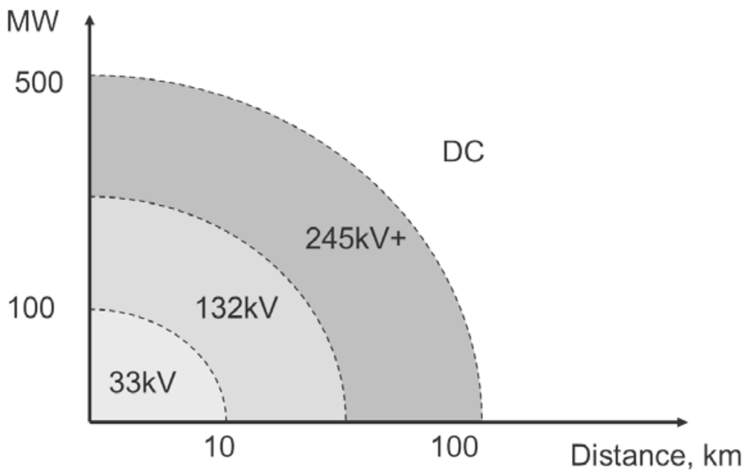


Figure 17: Distance - MW Diagram for power transmission solutions

Further cost savings may be available if it is possible to connect the project without using an offshore substation by either connecting the individual turbines directly to the shore or small clusters of turbines via MVAC. MVAC electrical configurations are only typically used by smaller wind farms (as a guide < 90 MW [40]) which are located with closest turbines quite close to shore (< 20 km). It should be noted that such an alternative method typically results in numerous cables being routed to the shoreline interface. This may incur extra planning considerations, but generally such an approach provides significant capital expenditure savings by avoiding the infrastructure cost associated with the manufacture, transport, installation and commissioning of an offshore substation. However as stated for larger capacity farms, that are far from shore, an offshore substation is typically required to mitigate electrical transmission losses and/ or reduce the number of export cables.

The transmission of power through HVAC technology is limited at longer distances due to the accumulation of a charging current in the export cabling system which reduces the actual power transmission capacity of the cabling system. For this reason, HVDC is used for large offshore wind projects which are located at significant distances from the near shore point (≥ 100 km) from where HVDC connections are economically viable. HVDC transmission technology is more traditionally used in inter-country connections for the bulk supply of power over a long distance. In comparison to HVAC connections, HVDC systems require two current conversions: once to convert the power from AC (Offshore wind farm inter array gird) to the HVDC transmission system and back to AC following landfall.

Such conversion processes are expensive, particularly as the favoured method of conversion for offshore wind farms (such as those converter stations presently installed in the German North Sea by the local transmission system operator TenneT - with HVDC systems provided by ABB and Siemens) is voltage source conversion (VSC) technology. This is advantageous for offshore wind farms in terms of providing grid support systems at the network interface which would not be possible using alternative current source conversion (CSC) technology used in older HVDC systems. The HVDC technology is only used in German offshore wind farms which are far from shore.

The high cost of offshore HVDC transmission experienced in Germany over the past five years is driving the industry to consider alternative connection methods for wind farms located further offshore. One alternative solution is Low Frequency AC (LFAC) transmission which doesn't' require large scale and costly offshore converter platforms. LFAC systems would transmit the power to shore via alternating current with a waveform with a lower frequency than the standard 50 Hz – typically 1/3 of the normal grid frequency (e.g. 20 Hz) which is already in commercial use onshore [41] [42].

Figure 18 provides a graphical demonstration of the distance from shore where LFAC would be considered to be a viable option for a 600 MW offshore wind farm, according to a recent DNV GL study on power frequency optimisation for offshore wind farms. However, it should be noted that LFAC designs have not yet been utilised on any commercial offshore wind projects.

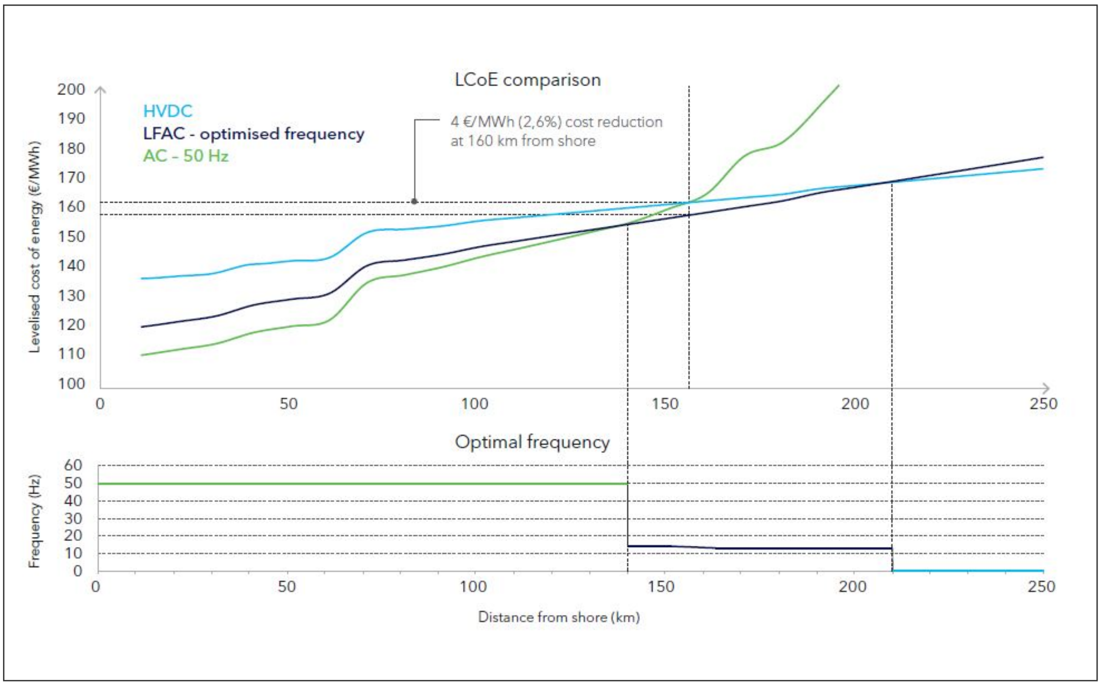


Figure 18: Cost of Energy Comparison of HVAC, LFAC and HVDC.

Source: **[24]**

In summary, there are four connection methodologies available for developers to connect offshore wind farms: these are MVAV (direct connection to shore without any offshore substation being present, HVAC (export via offshore substation), HVDC (export via offshore substation and converter platform) and LFAC connections.

Generally front end engineering designs (FEED) are undertaken to establish the exact criteria for a specific project and to determine the optimum electrical design on a project specific basis. This takes into account the expected cost, electrical losses and any additional grid code compliance equipment.

6.2.4 Best practice for electrical system design

In order to identify the optimum configuration and design of the electrical system, the electrical concept design study consists of the following stages:

1. Concept options identification and selection
2. Electrical design validation
3. Electrical system requirements

This process is represented graphically in the figure below:

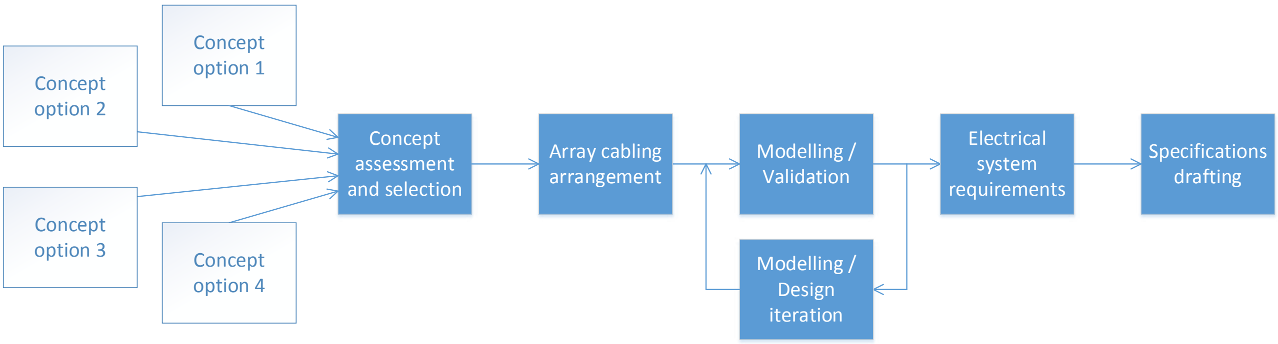


Figure 19: Electrical systems concept design process

Based on the wind turbine layout arrangement a high level assessment of available electrical technology solutions suitable for the proposed offshore wind farm site is conducted. Following identification of the various options suitable for the collection and connection of the wind turbine output to the onshore electricity network, costs along with a review of benefits and drawbacks of each option are to be assigned. In the next step the inter-array cable network will be, where possible, optimised with respect to technical and economic aspects and based on agreed boundary conditions. This analysis takes into consideration the planned locations of the wind turbines, the power curve of the chosen wind turbine generator (WTG) and the results from the wind measurements or energy yield calculation. Based on the results of the analysis the following cable parameters shall be determined:

- Quantity and cross-sectional area;
- Topology of the network (string configuration, loop configuration, etc.); and
- Number of turbines per circuit.

The best technical and economic network options will be evaluated in consideration to capital costs and electrical losses. The experience from former investigations based on reliability calculations has shown that the cost for energy not supplied to the onshore grid due to failures of electrical components can have a minor impact on the evaluation of the optimal network configurations.

Following concept selection, validation and enhancement of the (chosen) electrical system design is undertaken through power systems modelling study work. The aim of the electrical design validation is to demonstrate that the design operates satisfactorily over a range of conditions such that network operator requirements are satisfied and wind farm electrical infrastructure ratings are not exceeded. The design can then be taken forward to enable the drafting of specifications.

The validation process is mainly carried out using power systems analysis software. A simplified model of the network is constructed along with a model of the wind farm electrical system.

The remainder of this section provides a brief summary of the key parameters that might drive electrical system design concept selection:

- The scale of the project in terms of the maximum power to be exported, which along with distance from shore, is the primary driver to inform the decision on whether an offshore substation is necessary;
- Location of the project, in particular its distance from shore, and location of the onshore grid connection point;
- Electrical characteristics of the onshore grid connection point;
- The submarine cable route and preferred submarine cable installation methodology; and
- The potential site of the onshore/ offshore cabling interface.

6.2.5 High level electrical considerations for Gujarat

In India onshore renewable energy projects are connected to the grid at voltage levels of 33 kV, 66 kV, 110 kV and 132 kV, whereas large size project (> 70 MW [43]) are connected to the grid at 132 kV or 220 kV levels.

The wind energy policy of Gujarat mentions that power evacuation facilities (transmission network) for wind farms up to 100 km from the grid will be erected by the project developer at their own cost and beyond 100 km the power evacuation (transmission) facility will be erected by the State Transmission Utility (STU).

The voltage level for evacuation of wind power in the grid shall be at 132 kV and above.

In the draft policy for grid code, GERC mentioned the following criteria for transmission planning for renewable energy [43]:

- 50 MW capacity through 66 kV double circuit line of Aluminium Conductor Steel-Reinforced (ACSR) Dog conductor;
- 70 MW capacity through 66 kV double circuit line of ACSR Panther conductor;
- More than 70 MW capacity through 132 kV/220 kV/400 kV (based on geographical locations) double circuit line.

It is noted that the terminology here is more specific to onshore projects which use overhead lines to connect to the grid. The use of ACSR overhead lines is not applicable for offshore transmission.

Based on recent experience, the FOWIND consortium considers, that for an offshore wind farm with a capacity of 150 MW, connection via an offshore substation to a 220 kV node would likely be most suitable; whilst a higher capacity plant (504 MW) would require connection to a 400 kV system node. The highest AC connection voltage presently used in submarine cables for wind farms is a 220 kV operating voltage, so such an option would require a step up grid transformer at the onshore substation.

The Gujarat region has a number of operational transmission lines and substations near the coast which could facilitate offshore wind energy output [44].

Table 17 to Table 24 present a list of existing 132 kV, 220 kV and 400 kV substations in Gujarat near to the identified development zones. They give the point to point aerial distance to each zone as well as the voltage level. The existing load is not a limiting factor on the amount of generation which can be connected, which is dependent on the normal load flows in the area, and the capacity of local network to accommodate extra load and short circuit levels which may arise from the offshore wind generation connection.

Zone A: The proposed zone is near to the Junagadh and Amreli transmission zone. Substations near to the zone are listed in Table 17.

Table 17: Substations Near to the Shore in Zone A.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Dhokadava	220	48
Ultratech	220	23

Zone B: The proposed zone is near to the Amreli transmission zone. The nearest districts to the zone are Amreli, Bhavnagar, Surat and Valsad. Substations near to the zone are listed in Table 18.

Table 18: Substations Near to the Shore in Zone B.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Ultratech	220	26
Otha	220	25

Zone C: The proposed zone is near to the Junagadh and Amreli transmission zone. Substations near to the shore for this zone are listed in Table 19.

Table 19: Substations Near to the Shore in Zone C.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Talala	132	48
Dhokadava	220	28
Ultratech	220	8
Otha	220	47
Ambuja	132	17
Timbdi	220	28

Zone D: The nearest districts to the zone are Navsari, Surat, Bharuch and Vapi. The proposed zone is near to the Navsari and Bharuch transmission zones. Substations near to the zone are listed in Table 20.

Table 20: Substations Near to the Zone D.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Ambheta	220	36
Navsari	220	30
Mora	220	21
Vapi	220	35
	400	40
Bhilad	220	40
Atul	132	23
Sachin	220	26
Magarwada	220	26

Zone E: The proposed zone is near to the Valsad and Surat transmission zones. Substations near to the shore are listed in Table 21.

Table 21: Substations Near to the Shore in Zone E.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Vapi	220	59
Magarwada	220	53
Bhilad	220	54

Zone F: The proposed zone is near to the Surat, Bharuch and Bhavnagar transmission zones. Substations near to the zone are listed in Table 22.

Table 22: Substations Near to the Shore in Zone F.

Name of the Substation	Capacity (kV)	Approx. Aerial Distance Nearest Point (km)
Otha	220	33
Sagapara	220	50
Vartej	220	40
Dahej	220	14
Ankleshwar	132	48
Kosamba	400	41
Essar Steel	400	8
Navasari	220	43
Sachin	220	34
Bhestan	132	31

Zone G: The proposed zone is near to the Jamnagar transmission zone and districts near to the zone are Jamnagar and Porbandar. Substations near to the zone are listed in the Table 23.

Table 23: Substations Near to the Shore in Zone G.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Bhatiya	132	25
Ranavav	220	33

Zone H: The proposed zone is near to the Jamnagar transmission zone and district near to the zone are Jamnagar and Porbandar. Substations near to the zone are listed in the Table 24.

Table 24: Substations Near to the Shore in Zone H.

Name of the Substation	Voltage (kV)	Aerial Point to Point Distance (km)
Ranavav	220	32
Keshod	220	40

The existing transmission infrastructures may be sufficient to allow some development of offshore wind power in Gujarat but detailed studies are required to assess in full if some transmission upgrades would be necessary. To ascertain the exact requirement for transmission infrastructure for development of offshore wind power in the state of Gujarat, the following study/ analysis will be required. This will be touched upon under the FOWIND project's scope (Work Package 3):

- Identification of the most appropriate point of interconnection (POI) for connecting the offshore wind power to the transmission grid based on expected physical locations associated with the finalised offshore wind power project sites and 'strengthening' of grid node;

- Analysis of any additional electrical equipment / upgrades required on the surrounding transmission network for the connection of the available wind farm capacity – noting the effects on normal load flow, power quality short circuit levels using power system modelling software;
- Analysis of electrical equipment required for the connection of the available wind farm capacity (wind farm substation equipment to comply with grid code at point of connection etc.);
- From the above analysis, quantify the cost of integrating offshore wind power into the transmission grid while identifying the cost estimates associated with the following:
  - Transmission system network upgrades; and
  - Direct interconnection costs.
- Assess the feasibility of offshore wind power transfer capability via a dynamic assessment focused on the local transmission grid with specific focus on:
  - Transient rotor angle stability; and
  - Transient voltage stability.

6.3 High level installation consideration

6.3.1 Introduction

Various different transportation and installation concepts have been developed to optimise time spent on offshore installation works with the overall goal to reduce the logistic costs. The construction planning is predominantly factored by site conditions, vessels, ports, infrastructure and skilled personnel.

This section provides a high level overview of the key installation considerations for offshore wind developments in Gujarat.

6.3.2 Port and harbour considerations

Besides the main wind farm infrastructure, the port is one of the most important components in offshore wind construction. Therefore the following section provides a high level overview of: Potential port strategies, key parameters for selection and a high level port and harbour screening for the Gujarat.

6.3.2.1 Potential strategies

Ports handle manufacturing, storage and transportation of wind farm components. A port can be utilised as either a manufacturing port or marshalling port. In general a manufacturing port will have more prerequisites than marshalling port since it handles both manufacturing and assembly of components.

In an ideal world all manufacturing facilities would be located on the coast, within the port closest to the offshore wind farm. In this configuration the foundation or turbine installation vessel would cycle directly between the manufacturer's port and the offshore wind farm, and all necessary storage to accommodate fluctuations in installation rate would be accommodated within the manufacturers' premises.

In reality however, within offshore wind farm developments there is often a very large spatial distribution between the manufacturing premises and the offshore wind farm, and indeed these facilities are regularly located in other countries. In such cases, wind turbine components are first transported from the manufacturing port to the intermediate marshalling port and from there to the offshore wind project site.

6.3.2.2 Key parameter for selection

Each construction strategy places technical and logistical requirements on the port's infrastructure. It is hence necessary to evaluate each in detail to ascertain whether the port is suitable, with or without modification to accommodate any particular operation.

The following key aspects should typically be considered in the preliminary assessment of construction ports for Gujarat:

- **Distance to shore –** In general, offshore wind farm installation vessels have charter rates of several times those of cargo vessels, so to minimise overall installation costs, it is vital that voyage durations for the installation vessel are kept to a minimum;
- **Maximum vessel dimension** - The two main criteria with respect to vessel dimensions are water depth and potential berth length. They define the minimum requirements for the required installation vessel to berth;
- **Area for storage and heavy duty components -** Depending on the construction strategy a buffer stock for an indicated number of component sets or units might be required at the port; and
- **Intra connection -** The ports hinterland connection is another important aspect to be considered in the port assessment to ensure that components can be delivered to port for assembly and loading.

6.3.2.3 Port and harbour screening - Gujarat

The State of Gujarat has, with over 1,600 km, the longest coastline in India, and a lot of developed and protected harbours. In total 43 ports have been identified in the Gujarat region (see Figure 40). Out of these identified 43 ports, Kandla is a major port administrated by Kandla Port Trust (an autonomous body) on behalf of the central government. Diu and Daman are two minor ports under the central government. The remaining 40 ports are under the state government.

Out of the total 43 in the Gujarat region, 18 ports have initially been considered potentially suitable for any of the construction activities. However, the ports of Bhogat, Chhara, Mahuva and Vansi Borsi are proposed under development [45] and, hence have not been selected at this stage for further analysis. In addition, the ports at Diu and Alang have not been selected since they are small ports mainly involved in fishing activities and would incur significant capital investment costs. Out of the remaining ports seven have been identified with some potential.

Table 25 provides a high level overview of seven ports preliminary identified. A more detailed analysis of these ports will be undertaken during the future FOWIND infrastructure study.

Table 25: Overview of Port Characteristics.
Source: [45] [46] [47] [48] [49]

Port	Max Draft (m)	Closest Development Zones	Distance to Development Zones (km)	High level Port Characteristics
Dahej	13	G	10	The deep water port of Dehej is provided with a total berth length of 210 m, a developed broad gauge rail and road hinterland connection and transit as well as significant storage area.
Hazira	12	A / C	30 / 9	The port of Hazira is a well-developed deep water harbour with LNG, container and bulk terminals and significant container storage space. The broad gauge rail connection is not developed yet.
Jafrabad	4	A / B / C	23 / 24 / 9	The shallow water port of Jafrabad consists of an area of 25 hectares with a developed road connection and nearest airport is Diu in about 75 km distance. The broad rail connection ends at Rajula which is about 33 km from the port. The port is further provided with a quay length of maximum 450 m.
Nargol	16	G / H	22 / 16	Nargol is a substantial deep water port with four berths for container and general cargo vessels with a total length of more than 1,000 m and a significant storage area. Further developments of the storage area are in progress.

Pipavav	14.5	D / F	12 / 8	Pipavav is a well-developed deep water port with quay length of about 1,700 m and a storage area of 15.5 hectares. The port is provided with a road and broad gauge rail hinterland connection.
Porbandar	9.8	F	32	Porbandar is provided with broad gauge rail and highway connection. The storage area is around 24.1 hectares with a total berth capacity of approximately 380 m.
Magdalla	13.7	D / F	21 / 20	The deep water port of Magdalla is located in the south of Gujarat and is provided with a quay length of about 500 m and rail and road hinterland connection.

6.3.3 Construction vessel considerations

Construction of offshore wind power project requires specialised vessels. During the last years offshore wind has developed from a niche industry to an established independent industry sector. As a consequence, currently offshore wind projects utilise newly designed vessels which are specially built for the requirements of the offshore wind farm projects. In comparison, the first wave of offshore wind projects had to use installation vessels from adjacent sectors like civil engineering and the offshore oil and gas industry. It is anticipated that this might be the case in newly developing offshore wind markets such as India where utilisation and modification of vessels from adjacent sectors will be required until a sufficient supply chain develops.

6.3.3.1 Potential construction vessels

Dependent on the project specific requirements up to 18 different types of vessel are needed during the offshore wind farm project life cycle [50]. Some of the major vessel types are discussed in Table 26.

Table 26: Various Types of Vessels Used in Offshore Wind Construction.

Type of Vessel	Activity	Dimensions	Vessel Example
Survey Vessel	Geophysical survey and geotechnical survey as part of the required soil investigations	Length: 20-80 m Max. Draft: 5 m	 Fugro Voyager (worldmaritimenews.com)
	Smaller survey vessels are used to perform environmental impact assessment studies, UXO surveys and post-evaluation.	Length: 20-60 m Max. Draft: 5 m	 MS Reykjanes (marinetraffic.com
Turbine Transportation and Installation Vessel	Self-propelled installation jack-up vessels that can carry multiple turbines at a time and a required crane capacity of 500 t-1000 t. Depending on the decks and crane and capacity the same vessels are deployed for foundation installation.	Length: 80-160 m Max. Draft: 5 m	 MPI Advenure (marinetraffic.com)

Type of Vessel	Activity	Dimensions	Vessel Example
Turbine transportation and Installation Vessel	Towed installation Jack-Up Barge vessels that can carry multiple turbines at a time and a required crane capacity of 500 t.	Length: 20-60 m Max. Draft: 5 m	 Goliath (cherbourgescale.over-blog.com)
	Floating DP heavy lift cargo vessel	Length: 100-160 m Max. Draft: 8 m	 Jumbo Kinetic (gcaptain.com)
Foundation transport and installation vessels	Moored Heavy lift vessels that can carry one or several foundations at a time with a required crane capacity of up to 1000 t.	Length: 100-160 m Max. Draft: 8 m	 Stanislav Yudin (www.nrwbank.de)

Type of Vessel	Activity	Dimensions	Vessel Example
Foundation transport and installation vessels	Self-propelled installation heavy lift jack-up vessels that can carry one or several foundations at a time with a required crane capacity of up to 1000 t	Length: 100-160 m Max. Draft: 8 m	 Innovation (DNV GL)
Substation topside installation vessel	Semi-submersible or DP Heavy lift vessels with crane capacity of up to 14,000 t.	Length: 100-200 m Max. Draft: 31,5 m	 Thialf (www.hollandmarinelifts.com)
Offshore Supply Vessel	Multipurpose construction vessel to assist in the construction of offshore wind parks conducting the following tasks: • Transportation of cargo and personnel • Diving Support • Accommodation	Length: 20-140 m Max. Draft: 13.5 m	 OSV Relume (www.marinetraffic.com)

Type of Vessel	Activity	Dimensions	Vessel Example
Cable installation vessel	Cable installation vessels are used for laying and burial of sub-sea cables for intra array and export cables.	Length: 60-16 0m Max. Draft: 13.5 m	 Cable Innovator (ship-technology.com)
Crew Transfer Vessel	Transferring personal from shore to site and within the wind farm.	Length: 60-160 m Max. Draft: 13.5 m	 WINDEA ONE (www.windea.de)
Work boats & Tugs	Supports the work of other vessels as well as transferring tools and personal from shore to site and within the wind farm. Furthermore used as guard vessel.	Length: 20-140 m Max. Draft: 13.5 m	 Hunter (www.shipspotting.com)

6.3.3.2 Key parameters for selection

This section describes the typical key requirements and high level suitability criteria for installation vessels. Choosing the right vessel for a proposed offshore wind farm project is dependent on a number of key aspects. The following factors need to be considered:

Metocean conditions

Offshore wind farm sites witness harsh conditions which limit crane operations in terms of available time for lifting the components safely. As more and more offshore wind power projects are developed in deeper waters, larger and specialised turbine installation vessels are needed with longer jack-up legs or advanced floating installation using a dynamic positioning system. Tidal flows may also be a significant limiting factor as discussed in Section 6.1.6.3.

Soil conditions

Soil conditions of the proposed wind farm site play a significant role as many installation vessels are jack-ups. If the seabed in the areas of the proposed project consists of surficial silt layers, the installation may not be executed with jack-up vessels.

Component size

With increasing size of offshore wind turbines and foundations, vessels with higher crane and deck capacity are usually required.

Distance from shore

The distance between logistics marshalling or manufacturing port and the wind farm site is an important parameter. In general, offshore wind farm installation vessels have charter rates of several times those of cargo vessels, so to minimise overall installation costs, it is vital that voyages for the installation vessel are kept to a minimum.

6.3.3.3 Construction vessel screening

India has a total of over 700 offshore vessels with a total gross tonnage of over 800,000. Most of these vessels are used for the offshore oil and gas industry. To date no newly designed, offshore wind installation vessel exists in India. Table 27 provides an overview of offshore related vessels available in India and their potential scope for offshore wind installation.

Table 27: Offshore Related Vessels Available in India.
Source: **[51]**

Vessel Type	Potential scope	No. of Vessels
Offshore supply vessels	Construction support and supply vessels	113
Anchor handling tower support vessel (AHTS)	Construction support and supply vessels	4
Multi-purpose support vessel (MPSV)	Construction support and supply vessels	1
Motor stand-by vessel (MSV)	Work boats	1
Barges	Turbine and foundation transportation	39
Floating cranes	Turbine and foundation transportation and Installation Vessel	1
Dredgers	Construction support and supply vessels	36
Tug vessel	Construction support and supply vessels; work boats	322
Passenger service vessels	Crew transfer vessel	57
Port trusts and maritime board vessels	Requires investigation	95
Specialised vessels for offshore services	Requires investigation	38
Total		707

Based on the results of this vessel availability desk top survey, the following three opportunities for offshore wind deployments in the Gujarat region should be considered:

- Modifications of the existing oil and gas, fishing or civil engineering vessels specific to the requirements for both construction and operation and maintenance phases of offshore wind projects. This option should be considered at least for offshore support vessels and work boats.
- Design of specialised vessels for offshore wind project installation. The development of specialised vessels is largely dependent on the scale of deployment of offshore wind in India.
- Using the services of the existing European or Asian offshore wind vessels may be a favourable short term solution. This option should be considered for wind turbine, foundation and substation installation vessels.

6.3.4 Transportation and installation considerations

In general there are various possible combinations for the assembly, transportation and installation of wind farm components. To identify the combination which fits best to the requirements of the offshore wind developments in Gujarat we need to distinguish between the following phases of construction:

- Foundation
- Wind turbine generator
- Subsea cable
- Offshore substation

The following section provides a high level overview of the main transportation and installation strategies for these four phases.

6.3.4.1 Potential transportation and installation strategies

Foundation Transportation and Installation (T&I)

In order to capture a representative range of options in terms of transport and installations methods of an offshore wind project with corresponding marine operations and related transport and installation vessels and plant, four different strategies have been defined for transport and installation of the jacket and monopile foundation components. Based on the current results from Section 6.1 GBSs and other foundation concepts are not included here at this stage. For tripod foundations, on the basis of pre-feasibility, the installation strategy can be considered similar to Jackets. It should be noted that jacket foundations may be installed with pre-installed or post-installed piles. Post-installed piles have the advantage that one vessel could be used for the entire operation but the foundations will likely be heavier as a result of the attached pile sleeves. Pre-installed piles enable two vessels to be operating simultaneously (shorter installation time) and lighter jacket structures as sleeves are not required to resist pile driving forces. The majority of monopile foundations are installed with a grouted transition piece which offers some installation levelling tolerance. Nowadays, more and more projects in Europe and UK tend to use bolted flange connections.

The four broad T&I strategies can be defined as follows:

1. **Feeder barge and jack-up concept**

   The first foundation and most common installation strategy follows a rather standard approach by which foundation components (jackets and piles or monopiles and transition pieces) are transported from the procurement base either direct to the offshore wind farm, or to a marshalling port by towed barges. The same transport means is then used to deliver the foundations from the marshalling port to the project site. A standard small jack-up vessel will be on site and jacked-up at location, where the feeder barge will go alongside for the jack-up to lift-off piles and carry out the installation works.

2. **Jack-up concept**

   Opposite to installation concept 1; foundation components are transported from the procurement base directly to the offshore wind farm site by special purpose build jack-up vessels. Depending on the chosen foundation type and the size of the foundation, such vessels are typically able to carry up to three sets of foundations (e.g. Innovation at Global Tech I, Germany). The same vessel will be used for the installation works on site.

3. **Floating Installation A**

   The second strategy for the T&I of foundations follows a rather innovative approach. In this case a heavy lift cargo vessel (HLCV) transports piles from the procurement base directly to the project site where it carries out all pre-piling operations. In comparison to dumb barges, the use of HLCV allows for faster delivery rates even over relatively long transit distances. The same rationale and approach is followed for T&I of jackets by means of a heavy lift vessel (HLV). Grouting of the foundations will follow by means of a standard dynamic position offshore supply vessel (DP OSV).

4. **Floating Monopile Installation B**

   In the third case the monopiles are sealed at both ends and towed from the procurement base or the construction port to the project side by tugs. A floating crane vessel either on DP or moored vessel will carry out pilling operations at location.

Wind turbine generator T&I

In general turbine components may be transported from the staging port/manufacturing port to the installation site in one of the following two main strategies:

- Transport and installation of turbine components; or
- Transport and installation of fully assembled turbines.

Figure 20 provides an overview of the potential WTG installation concepts following the two main strategies.

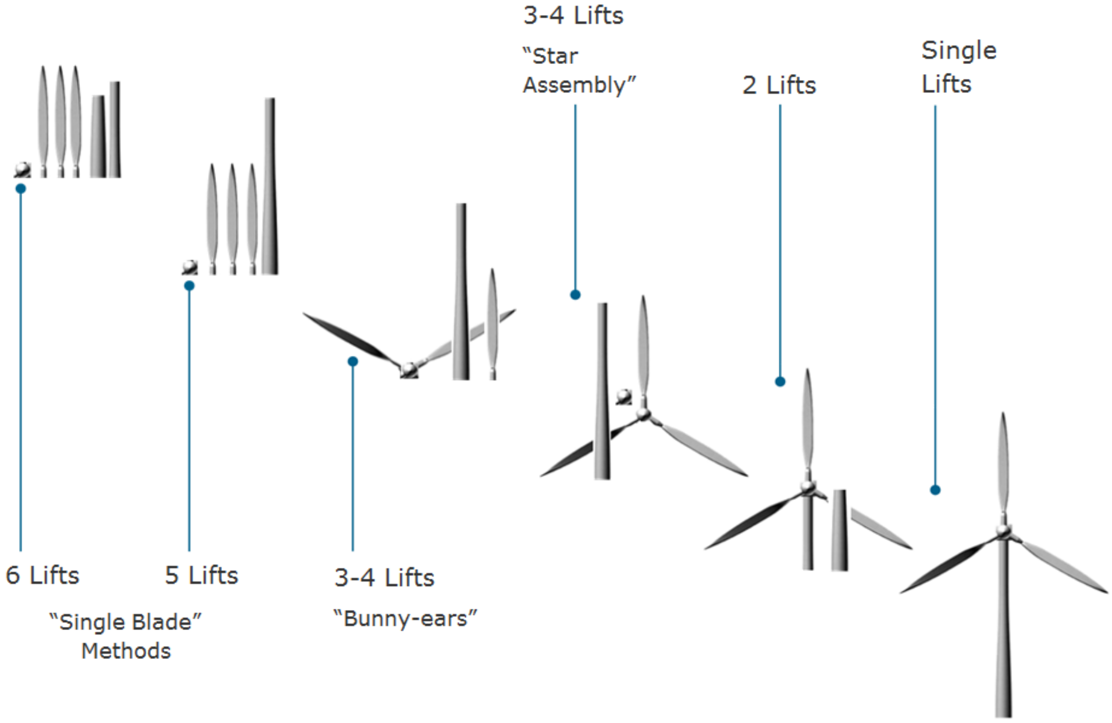


Figure 20: Overview of WTG Installation Concepts

The remainder of this section describes two main installation strategies in more detail.

1. **Transport & installation of turbine components**

This example is the most common WTG T&I strategy. The various key wind turbine components (e.g. blades, nacelle, hub, tower sections) are pre-assembled in the controlled environment of the port and then transported to the project location. The first four scenarios from left to right in show offshore installation concepts where the WTG components are sequentially installed offshore. In Europe early projects commonly adopted the "bunny-ears" method but this has largely been abandoned due to large space requirements on jack-up vessels. The two most common approaches to date are the "single blade" and "rotor star" methods. Single blade installation is common for WTG MW classes < 4 MW and is efficient for on-deck storage. However, for larger WTGs >5 MW this method puts significant loads on the turbine's drive-train hence it is common to adopt the rotor "star assembly" method. Assembly at the offshore installation site reduces the risks associated with transportation of fully assembled turbine, but involves the risks associated with turbine assembly in the marine environment.

2. **Transport & installation of fully assembled turbines**

   Alternatively the whole turbine unit could be pre-assembled in port and transported and installed offshore in one operation (see, above). This is beneficial in terms of minimising marine operations however the operation involves a very heavy and complex lift. The operation would typically be heavily restricted by metocean limits and require specialist temporary "soft-landing" systems to be pre-installed on the foundation. This has only seen very limited use in Europe (Beatrice Demonstrator, UK). However, in China this operation has been widely used in their early projects.

Subsea cable T&I

Inter-array cables (IACs) and export cables are typically pre-cut and stored on individual cable drums. These are then transported by a standard cargo vessel to the marshalling port and stored there to build up a sufficient buffer stock. Cable laying and burial is carried out by a cable installation vessel or a modified DP OSV fitted with corresponding cable-laying equipment. Alternatively, cables can be delivered straight to the cable-laying vessel from the cable manufacturer's delivery port.

Offshore substation T&I

There exist a number of strategies for T&I depending on the offshore substation substructure and topside concept, these include:

1. **Lifted Substructure and Topside** – this is the most common installation method for HVAC offshore substation (OSS) to date where both the substructure and the topside of the OSS will be transported from the manufacturing base to the marshalling port, or straight to site, aboard a towed offshore barge. When a suitable weather window is available, the OSS substructure will be delivered to site aboard the barge, where it will be lifted off and installed by a heavy lift crane vessel (HLCV). If using a pre-piling approach, this will follow a similar method with corresponding vessels as with the WTG foundation installation. Once the substructure is completed, the OSS topside will be transported to site and installed, often done using the same HLCV as for the foundation. The topside installation will typically be the heaviest lift in an offshore wind project, with topside weights in the region of 2000 – 4000 tonnes. In topside design the installation lift will often be the driving load case, hence requires careful consideration and handling during lifting operations.

2. **Self-installing Substructure and Topside** – a novel method (used in BARD Offshore 1, Germany) to avoid the use of HLCVs. Both the substructure and buoyant topside are designed to float and then towed to site; where in first step the substructure is lowered to the seabed and following this the topside is raised clear of the water using an in-built jacking system.

3. **Subsea Base Frame and Floating Jack-up Topside** – in this method a lattice base frame (substructure) is pre-installed on the seabed and the buoyant/ enclosed topside is floated over and using in-built jack-up legs is installed and raised clear of the water (used for the BorWin Beta HVDC converter station, Germany).

4. **Topside Float-over Installation** – this approach has strong synergies with the O&G industry in the Gulf of Mexico and the Middle East. A jacket substructure is pre-installed with two up-stands. The heavy topside is then floated out by barge. During high water the barge is located between the two jacket up-stands, de-ballasted and the topside lowered and located into position. Following this the topside is jacked-up clear of the water (used for SylWin Alpha HVDC convertor station, Germany).

6.3.4.2 Transportation and installation planning

It is recommended to commence site-specific transportation and installation planning during early project development stages, before critical design decisions are made. As highlighted by Figure 12 in Section 6.1 the T&I strategy has strong interconnections with key project packages, such as foundations, turbines and electrical systems. The T&I planning procedures often include:

- Estimation of the main components weight and dimensions;
- Port assessment;
- Installation strategy;
- Vessel assessment and selection;
- Estimation of the installation program;
- Estimate of operation cycle times; and
- Estimation of the installation costs.

The T&I strategy should be optimised for the specific conditions of each individual project site. Careful consideration of the metocean conditions, transit distances and vessel characteristics is necessary. Metocean conditions and weather window downtime can be a significant limiting factor, for example including:

- Waves – limiting jack-up vessel operation, floating operations and access;
- Wind speeds – limiting turbine blade/ rotor lifts and other lifts; and
- Water current – limiting jack-up operation and piling operations.

Considering Gujarat’s climatic conditions, the summers are extremely hot and dry with daytime temperatures around 49 °C (120 °F) and at night not lower than 30 °C (86 °F), while the monsoons are quite strong and can cause severe floods [52]. Therefore it is important to consider an adequate amount of weather downtime within the overall T&I schedule. Furthermore, schedule planning should consider monthly weather fluctuations during the year, like cyclones (Typhoons). With a typical share of up to 20% of the total CapEx of an offshore wind project [53], T&I expenses have a significant impact on the profitability of the wind farm. Therefore optimising the strategy and reducing potential downtime due to weather can support cost reduction and mitigation of schedule over runs during the T&I phase of the project.

6.4 Operation and Maintenance considerations

6.4.1 Introduction

As the name suggests, the operation and maintenance activities of an offshore wind farm can be divided into two main tasks:

1. Monitoring, controlling and coordinating the wind farm operations; and
2. Maintenance activities of the turbines and the balance of plant (BoP), which are typically sub-categorised into:

- **Scheduled maintenance**: This maintenance category comprises any task which is pre-planned at the design stage and normally requires the turbine to be temporarily stopped for maintenance work to be undertaken. Offshore scheduled maintenance intervals of 1 year are emerging as the normal practice in contrast to the quarterly or bi-annual approach typically witnessed onshore. This reflects the greater expense, risk and effort associated with offshore access. These scheduled works are often conducted on a seasonal basis, with the bulk of work being carried out in the summer to maximise the probability of access and minimise lost production. This approach may lead to the need for additional resources (vessels, equipment, and technicians) to be brought in during these campaigns;
- **Unscheduled maintenance**: Any unplanned maintenance activities resulting from a failure of a system, sub-system, or component fall within this group. The level of corrective action, and the impact of the unscheduled maintenance upon the wind farm availability, depends on the severity of the failure. Most failures occur within the wind turbine generator systems and only affect the output of individual turbines, while failure events within the substations or cables occur far less frequently but can have a greater impact on the number of turbines affected depending upon their location.

Nowadays, developments in advanced control and monitoring systems enable operators to undertake routine checks of operational data and to control the turbines from a remote onshore location, while scheduled and unscheduled maintenance works require the transportation and transfer of technicians to the offshore structures. The access logistics associated with these maintenance activities, are one of the most significant operational challenges facing the offshore wind energy market.

This section provides an overview of the key offshore wind O&M considerations and estimates high level operational expenditure (OpEx) costs and predicted availabilities for offshore wind developments in Gujarat.

6.4.2 Typical O&M agreements

To undertake these scheduled and unscheduled maintenance activities, the typical approach seen in the offshore wind industry is for wind turbine suppliers to provide a service and warranty agreement (SWA) which covers all scheduled and repair activities of the wind turbines for the first years of the project's operation (typically 5 years since takeover date of the first turbine). The agreement often guaranties a production-based or a time-based availability of the project. For these purposes, the wind turbine availability of the project is assessed annually and the wind turbine supplier is considered to have met the warranty if the measured yield or time during the period of assessment is equal to or greater than the warranted level. Compensation in the form of liquidated damages is payable if production or available time is below the warranted level. In some cases, the availability warranty also includes an incentive mechanism whereby the wind turbine supplier is eligible to receive a percentage of the revenues from energy produced above the warranted level during the assessment period.

For the rest of the project's lifetime, it is typical for the wind turbine suppliers to offer an extension of their services in the form of an O&M Agreement (OMA). Some current operating projects are reaching this post warranty period and are opting for extensions on the wind turbine suppliers' contracts whilst for other projects, owners are taking over the provision of these O&M services.

It must be noted that in the current industry, the SWA and the OMA agreements do not cover the turbine sub-sea structures, wind farm array cables, the offshore substation and other balance of plant and transmission infrastructure. For these assets, third party contractors are typically hired.

6.4.3 Access methodologies

Current and planned offshore wind farms around the world are maintained by a variety of different operational strategies and access methodologies. Such access strategies are predominantly concerned with the transportation of technicians, parts and equipment from the operations and maintenance base and their subsequent safe transfer between the vessel and the offshore structures.

Access strategies can be classified under three main categories:

- Onshore-based marine access (e.g. work boats, SWATH vessels, etc., based at a coastal port);
- Helicopter access; and
- Offshore-based marine access (e.g. offshore accommodation platforms, floatels etc., where technicians live offshore).

For marine access, sea-state during transfer onto the structures is usually the primary determining factor, typically quantified in terms of significant wave height (Hs) in units of meters. Other potential limitations include current, wind speed, sea ice, visibility and water depth. These restrictions result in the occurrence of weather windows during which all these factors are within the limitations of a particular vessel or access solution. As a result of the limited weather windows in which access may be achieved, even small unscheduled failures or diagnosis visits can lead to the accruement of considerable downtime and lost production, particularly as periods of onerous weather and limited access are likely to coincide with periods of high wind and therefore high potential for energy generation.

To date, most projects utilise onshore bases and typically use work boats to transport technicians from port to the site where they transfer onto the offshore structures using a simple step over approach. In more advanced strategies, the uses of advanced vessels or helicopters are emerging for some existing and planned projects. Furthermore, as projects begin to be based further offshore, work boats may also operate from fixed offshore bases, floatels or motherships to substantially reduce the time required for transiting to and from site. Such offshore-based approaches require technicians to live for some or all of the year on offshore accommodation near the vicinity of the wind farm, whether fixed or floating, in a similar manner to the approach adopted in offshore oil and gas.

6.4.4 O&M vessels

A wide range of conventional and specialist vessels are currently available to provide frequent personnel transportation and access to offshore wind farm developments from an onshore location. These vessels vary in capacity, speed, and significant wave height (Hs) transferring capabilities and include:

- Quick response vessels (e.g. rigid inflatable boats (RIB));
- Work boats (traditional catamarans);
- Small water-plane area twin hull vessels (SWATH vessels); and
- Hovercrafts or amphibious vehicles (for ice or inter-tidal conditions).

A brief description of the vessels relevant to Gujarat is provided in the following sub-sections.

6.4.4.1 Quick response vessels

There are a range of rigid inflatable boats (RIBs) and other lightweight vessels currently available for offshore wind farm operations. These vessels are small and designed for light work and as quick response during installation and operation activities offshore. The vessels are typically in the range of 5 to 15 m length and capable of transferring up to 12 technicians and of achieving speeds of approximately 35 knots, well in excess of those attained by most aluminium catamarans and larger workboats. Quick response vessels will typically dock with turbines and other structures in a similar manner to that utilised for work boats; however, given the generally narrower bow of such vessels, they may employ a different fender design for docking with the boat landing.

Figure 21: Quick Access Vessel. Source: DNV GL

6.4.4.2 Work boats

Work boats form an integral part of O&M strategies for currently operational projects and are typically larger and more comfortable than the quick response vessels. The vessels are typically in the range of 17 to 24 m length and capable of transferring up to 12 technicians and of achieving speeds of approximately 30 knots. They are typically designed with large foredecks to allow plenty of space and flexibility for transporting components and equipment. This arrangement also means that all items are located underneath the turbine davit or nacelle crane when the vessel is in position against the boat landing. The maximum size of parts, tools and consumables that may be transported is usually governed more by the lifting capacity of the davit or nacelle crane on the turbines than by the deck capacity of the work boat.

Industry-quoted figures suggest that work boats may typically be used to transfer technicians to offshore structures in up to ~1.5 m Hs conditions; however, operating experience suggests that this is often not achievable, especially for smaller vessels.

Figure 22: Windcat *MK IV* during Transit (left) and Turbine Transfers' *Rhoscolyn Head* (right).

6.4.4.3 SWATH vessels

Small water-plane Area Twin Hull (SWATH) vessels perform turbine transfers in the same manner as work boats, but due to their hull design are generally more stable than typical monohull or catamaran vessels. This is due to their specialist hull design which provides the majority of the buoyancy well below the surface, thus minimising the impact of the vertical motion of the waves on the vessel. For this reason the draft of SWATH vessels tends to be significantly greater than conventional monohull or catamaran vessels. This can cause access difficulties at very shallow sites and harbours and hence may place restrictions on the service base used.

Figure 23: SWATH Vessel on Trial

Figure 24: German Pilot SWATH Vessel *Dose*

As with work boats, SWATH vessels feature specially designed bows and fenders which are used to dock with the vertical tubular spars of the boat landings to enable personnel to step between the vessel and the structure.

6.4.5 O&M port

Wind farm operators use the nearest port which meets the minimum specific requirements to serve as an O&M port to minimise the transit time and time lost due to bad weather. Typically, a port should be able to meet the following requirements to serve as an O&M port for the offshore wind farm [54] [55]:

- O&M facilities should be available 24/7 and 365 days a year;
- Availability of a non-drying harbour for uninterrupted access;
- 20 m berth for each support vessel. The number of support vessels required will vary depending on the capacity of offshore wind farm and its distance from shore;
- Ramped and stepped access to facilitate simultaneous transfer to multiple vessels;
- Lifting equipment like forklifts (600 kg) and small cranes (1 tonne) to move components from the harbour to service vessel;
- Access to fresh water, electricity, fuelling facilities;
- General waste disposal and waste water disposal facilities; and
- Workshop, with provision for hot work (including welding, angle grinders), clamping equipment, workbench areas and tool storage.

DNV GL has considered the distance of nearest ports for each of the identified zones in order to prepare a heat map of ports in Gujarat. Based on this data and the evaluation criteria mentioned above, suitable ports for O&M were identified for each zone. The results are given in Table 28. However, a detailed study and analysis needs to be carried out in order to draw final conclusions.

Table 28: Suitable O&M Port for Each Identified Zone.

Zone	Port	Distance (km)
A	Pipavav	23.7
B	Pipavav	23.9
C	Navabandar	9.4
D	Hazira	12.3
E	Nargol	40.9
F	Hazira	9.6
G	Dwarka	9.6
H	Porbandar	15.6

6.4.6 Selection of suitable O&M strategy

In order to select the most suitable O&M Strategy DNV GL has used its in-house model: "O2M-Optimisation of Operations and Maintenance" to simulate a variety of O&M strategies at each of the selected zones. For each of the zones, the approximate optimum O&M strategy has been derived as that corresponding to the minimum O&M opportunity cost, calculated as a long-term average, as follows:

Total O&M Opportunity Cost = Direct O&M Costs + Lost Production Costs

This cost formula takes account of both the level of investment in the O&M of the project as well as the value of the energy produced. Minimisation of total opportunity costs therefore represents the maximisation of profits from the wind farm, given the assumptions outlined in this report (illustrated in Figure 25).

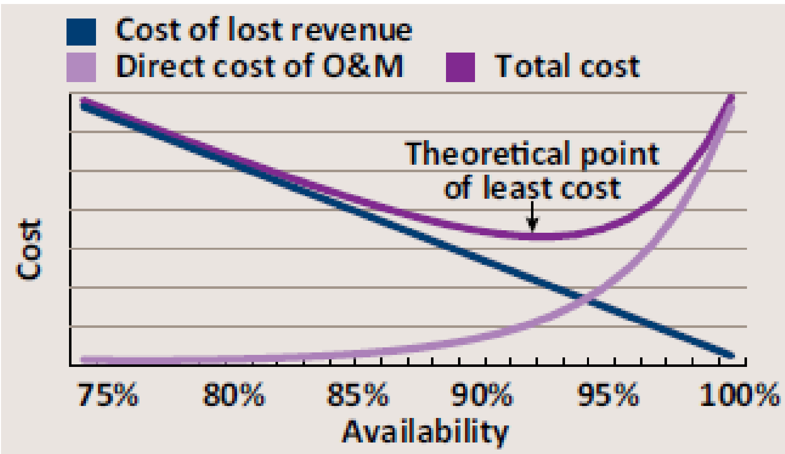


Figure 25: Illustration of balance between cost and lost revenue Source: **[56]**

For these purposes, the main assumptions presented in Table 29 have been considered.

Table 29: O&M main assumptions per Zone.

Zone	Long-term Mean Significant Wave Height - Hs (m)	Suitable Port	Average Distance to Port (km)
A	0.9	Pipavav	23.7
B	0.6	Pipavav	23.9
C	1.0	Navabandar	9.4
D	0.6	Hazira	12.3
E	0.8	Nargol	40.9
F	0.4	Hazira	9.6
G	1.5	Dwarka	9.6
H	1.4	Porbandar	15.6

It must be noted that due to either the proximity to the coast or the low long-term mean significant wave heights estimated at the identified zones, the use of helicopters or motherships is not envisaged to prove optimal for most scenarios. The inclusion of helicopter operations to support wind farms can be of significant relevance for a large number of turbines (for example for the 126 x 4 MW turbines) but will prove suboptimal for the rest of the configurations with a lower number of turbines (25, 38 and 84). However, due to the significant logistical and regulatory complexity added to a project and related to helicopter operations, it has been deemed appropriate to rule out these strategies and assume that all first offshore wind projects in India will be based on the most proven work boats access methodologies.

6.4.7 OpEx and availability estimates

The results of the analyses, detailed in Section 6.4.6 considering only work boats operations, are presented in Table 30 to Table 33 for the project configurations of 150 MW and 504 MW for each generic wind turbine capacity under consideration.

Table 30: OpEx and Availability Estimates for a 150 MW wind farm (generic 4 MW turbine).

Zone	OpEx (mINR per annum)	Wind farm availability (%)
A	1,241	94.4
B	1,226	94.6
C	1,207	94.5
D	1,188	94.7
E	1,282	94.2
F	1,180	94.7
G	1,450	89.8
H	1,400	91.3

Table 31: OpEx and Availability Estimates for a 150 MW wind farm (generic 6 MW turbine).

Zone	OpEx (mINR per annum)	Wind farm availability (%)
A	1,041	94.4
B	1,036	94.6
C	1,033	94.5
D	1,035	94.6
E	1,050	94.2
F	1,035	94.7
G	1,260	89.7
H	1,142	91.0

Table 32: OpEx and Availability Estimates for a 504 MW wind farm (generic 4 MW turbine).

Zone	OpEx (mINR per annum)	Wind farm availability (%)
A	4,115	94.1
B	4,066	94.6
C	4,002	94.1
D	3,941	94.6
E	4,251	94.1
F	3,911	94.6
G	4,808	89.6
H	4,642	92.4

Table 33: OpEx and Availability Estimates for a 504 MW wind farm (generic 6 MW turbine).

Zone	OpEx (mINR per annum)	Wind farm availability (%)
A	3,497	94.3
B	3,480	94.7
C	3,470	94.6
D	3,477	94.9
E	3,529	94.0
F	3,477	94.9
G	4,235	90.0
H	3,836	92.5

7 HIGH LEVEL PRELIMINARY PROJECT COSTING

7.1 Introduction

The development of offshore wind energy is affected by a wide range of interconnecting factors. Wind resource is the most significant factor affecting offshore wind Levelised Cost of Energy (LCOE). Sites with a good wind climate generally exhibit a lower LCOE.

The objective of this section is to obtain some high level LCOE estimates for the potential offshore wind development zones. Key baseline assumptions are discussed identifying key variables which are either fixed or optimised based on the assumed scenario. This includes turbine capacity, wind farm capacity, foundation type and electrical infrastructure.

This is followed by a discussion on the cost modelling approach and assumptions, which for the purpose of this high level project costing exercise assumed UK cost estimates only (considered to be a mature offshore industry). The LCOE results for each identified zone are presented in both table format and a LCOE heat map.

7.2 Cost of Energy baseline assumptions

Given the size and complexity of offshore wind farm development, it has been necessary to make a number of key assumptions, regarding project definition, to facilitate the determination of capital expenditure (CapEx), operational expenditure (OpEx) and annual energy production (AEP) across the identified potential development zones within the Indian State of Gujarat. This allows values to be derived for various technological cost drivers, whilst retaining a reasonable number of calculations during the modelling. Levelised Cost of Energy (LCOE) has been calculated for individual geographic locations within each zone at a resolution of 2 km.

DNV GL has used its offshore Cost of Energy (COE) model with site condition information based on publically available information to calculate preliminary COE estimates. The following key dimensions have been varied:

Table 34: Key dimension variables.

	Type	N° Options	1	2
Turbine capacity	Fixed	2	Generic WTG 4 MW	Generic WTG 6 MW
Windfarm capacity	Fixed	2	504 MW	150 MW
Foundation type	Optimised	2	Monopile	Jacket
Electrical infrastructure	Optimised	2	132 kV	220 kV

7.3 Project capacity

An indicative project capacity of 150 MW and 504 MW has been assumed in the modelling undertaken for each zone. The 150 MW and 504 MW project capacity has been used to provide a breakdown of costs (see Section 7.8). Whilst the 504 MW project capacity only, is represented as COE heat maps (see Section 7.9). This is considered broadly representative of typical European commercial offshore wind developments, and allows scale effects to be taken into account in the modelling. This capacity is a result of either 126 x 4 MW WTGs or 84 x 6 MW WTGs. Where applicable, cost calculations are based upon the infrastructure required by a project of this capacity; for example, in the sizing of offshore substation(s) and export cable(s).

7.4 Wind turbine size

Two sizes of wind turbine generator (WTG) have been considered in the modelling: 4 MW and 6 MW (see Section 5). These capacities are representative of established (4 MW) and current (6 MW) offshore wind turbine design; a number of European projects have been installed with WTGs of the order of 4 MW, and the first development featuring large rotor (> 150 m) 6 MW WTGs have been installed at a couple of offshore wind farms (54 x Repower 6 MW at Thornton Bank II and 2 x Siemens 6 MW prototypes at Gunfleet).

Cost functions have been developed which take into consideration the technical and economic implications of both WTGs with regard to supporting infrastructure and energy production.

7.5 Wind turbine spacing

An idealised project layout is assumed, and wake effects and array infrastructure requirements calculated based on this; project-specific layout design would take into account local factors and likely contribute to reduction in Cost of Energy (COE). Nevertheless, application of this approach across all points is consistent and considered reasonable for this level of modelling. The idealised layout incorporates turbine spacing of 8 rotor diameters for the 150 MW wind farm capacity scenario and 7 rotor diameters for the 504 MW scenario. The required area for each scenario has been scaled accordingly in order to achieve a constant capacity “density” of 6 MW/km^2. This is considered representative of current offshore development practice, and functions describing cost elements such as intra-array electrical infrastructure and energy production are calculated based on this density.

7.6 Cost modelling approach

The DNV GL model is used to derive the Levelised Cost of Energy (LCOE) for each location, based on its physical and technological characteristics as briefly described below. The COE calculated should be considered representative and is purely based on the assumed physical and environmental characteristics, as well as assumptions regarding the technologies to be deployed. It would be expected that COE could change following detailed project engineering and development effort; however, the analysis enables comparison between locations and insight into the relative merit of each zone.

The model calculates contributions to the overall Cost of Energy from three cost centres:

- Capital expenditure (CapEx);
- Operational expenditure (OpEx); and
- Annual energy production (AEP).

The components of these cost centres are described in the following tables.

Table 35: CapEx cost centres.

Cost element	Model description
WTG procurement	Costs are informed from market pricing data to which DNV GL has been privy during the course of commercial consultancy work. Costs are for the supply of complete WTGs, i.e. nacelle, rotor and tower.
WTG installation	Installation costs are considered in the model as a function of vessel day rate (itself a function of water depth and lift height and capacity), duration of operations and weather allowance. These costs have been informed by time-domain weather modelling, and include provision for waiting-on-weather.
Substructure procurement	Procurement of substructures (or foundations) for the wind turbines are considered in the model for two categories of competing solutions: monopiles and jacket structures. Costs for each concept are derived for each site under consideration, as a function of water depth.
Substructure installation	As per the "WTG installation" category.
Intra-array infrastructure	Comprising the medium voltage cables required to connect individual circuits of wind turbines to the offshore substation within the project site. Total length is determined taking into account turbine separation plus an allowance for routing, with unit rate cost assumptions for supply and installation.
Offshore substation	Comprising supporting substructure/ foundation, platform topside, main power transformers, high voltage and low voltage switchgear, reactive compensation, ancillary electrical plant and miscellaneous equipment. Sized for wind farm capacity and export infrastructure technology.
Export/ transmission infrastructure	Transmission or export cabling cost is driven by distance to shore and onshore grid connection point, with the number of cables and voltage determined by project capacity as well as export distance.
Onshore electrical works	Onshore electrical works incorporating the project substation required at the onshore grid connection point, to include all transformers, switchgear and reactive compensation equipment as required.
Project costs (development, management, installation, decommissioning)	Project costs are assumed to comprise those associated with development expenditure, contractor design and profit, project management during the execution phase and construction insurances as a flat rate of 5% of total CapEx. Consideration has also been given to the decommissioning costs which are assumed to be approximately 50% of installation capital cost. This cost has been discounted over the lifetime of the wind farm (assumed to be 20 years).
Contingency	A flat rate for additional costs incurred during construction and commissioning, assumed as a flat rate of 5% of total CapEx. This is considered to be an appropriate value for projects at financial investment decision (FID).

Table 36: OpEx cost centres.

Cost element	Model description
WTG O&M	Wind turbine operations and maintenance (O&M) costs comprise the scheduled and unscheduled works required on wind turbines during the operational phase. Cost functions are driven by number of WTG units, distance to the nearest O&M port and the mean significant wave height, which affects access offshore. These costs have been informed by time-domain weather modelling (see Section 6.4.7). The cost modelling includes assessment of the optimal O&M strategy using work boats only to minimise Cost of Energy, and includes the cost of this strategy in the COE calculations.
Balance of plant (BoP) expenses	Nominal allowance to cover inspection and maintenance of BoP infrastructure, comprising cables, substations and substructures.
Fees, taxes, payments, administration	Nominal allowances are applied to cover operational functions including: • Management fees • Insurance • General administration and support • Bank fees
Grid charges	No grid charges have been applied in the modelling; grid charges may be expected in practice, but have been excluded for clarity.

Table 37: Energy production.

Cost element	Model description
Net energy production	Net energy production is estimated within the model. Net capacity factor (NCF) is determined, based on: Generic WTG technology, wind turbine spacing and the project site mean wind speed. NCF is combined with the ideal energy output of the wind farm to derive a net energy production value considering wind climate and internal wake losses only. Further losses (see below) are taken into account to derive a final net energy output. It should be noted that the energy calculation performed is high level and does not replicate a full energy production assessment (see Section 5.7 for further details).
Wind Farm Availability	The losses associated with wind turbine and BoP downtime are accounted for via an availability efficiency. This is determined from the results of the time-domain O&M analysis.
Electrical and other losses	Electrical system losses are estimated as a function of electrical concept and distance from grid. A further nominal allowance is made to account for all other sources of energy losses such as blade degradation and high wind hysteresis (see Section 5.7 for further details).
Net energy output	All losses above are evaluated as a total efficiency for the project and this is applied to the gross energy out to yield net annual energy output.

Both installation and O&M modelling use bottom-up methods to estimate an overall cost for the works; these models therefore tend to produce a lower-bound (optimistic) result for these elements due to the failure to capture factors such as poor decision making, human error, equipment failures, contractual disputes and other unforeseen events.

The model specifically excludes the following non-exhaustive site-specific factors:

- Site-specific development costs such as unexploded ordnance surveys and removal;
- Site-specific seabed preparation costs, such as scour protection or soft sediment removal;
- Specialised cable burial and/ or protection other than ploughed burial; and
- Network upgrade works.

A simple discounted cash flow model is used to derive the Cost of Energy. A discount rate of 10% is applied in the model; this is considered broadly reasonable for offshore wind development, although DNV GL notes that individual projects may utilise alternative values and hence Cost of Energy may change as a result.

7.7 Key assumptions and caveats

The following key assumptions and caveats have been made and must be taken into account when viewing the results:

- The model used assumed UK cost estimates only, such as development expenditure (DevEx), support structure supply and installation CapEx, electrical infrastructure CapEx, turbine supply and installation CapEx and operational expenditure. Local Indian cost estimates, for example relating to material or labour costs, have not been considered; this may be done as part of a future update;
- The modelling calculates an average COE for the indicative project based on the parameters of each modelled location i.e. assuming that the complete project exhibits the same water depth, metocean conditions and wind climate as that defined at the reference point. It should not be assumed that the Cost of Energy of a particular project can be inferred from the averages of the reported COE values corresponding to the chosen area. However, this approach was chosen to provide an indicative distribution of cost of energy across the defined zones;
- The optimised COE is representative and should not be considered to necessarily represent the actual Cost of Energy of a realised project. For example, effective development and front end engineering studies can yield a significant reduction in cost of energy when compared to the generalised modelling undertaken here;
- Site climate conditions, such as wave characteristics, used in the modelling are based on publically available information and have not been independently verified;
- Areas with water depth greater than 70 m are currently considered not commercially viable for fixed foundations for offshore wind. COE values for these points have therefore not been reported. Note: This does not affect any of the identified potential zones in Gujarat, and affects only a limited number of data points in Tamil Nadu;
- Areas in water depth less than 5 m are assumed to have periods in a year when the lowest astronomical tide (LAT) plus tidal range is greater than the 3 m required for the installation of monopile or jacket foundations.

The results of the COE modelling are presented in Section 7.8.

7.8 Project cost estimates

The modelling described in Section 7 has been undertaken in two phases:

1. Modelling of individual locations within each zone on a 2 km resolution, for a 504 MW project comprising 4 MW and 6 MW WTGs. For this assessment, given the number of discrete calculation points, an idealised weibull distribution has been used to represent the wind climate at each point. Weibull distributions were scaled to the estimated mean wind speed at each point.
2. Zone-averaged values for input parameters such as water depth and wind speed, to represent and indicative wind farm within each zone, thus providing a breakdown of costs to be presented. For this, a more representative wind climate based on modern era retrospective reanalysis (MERRA) data was used. Cost modelling was undertaken for 4 MW and 6 MW WTGs, comprising 504 MW and 150 MW wind farms; the latter is broadly indicative of smaller demonstration projects which may be expected to precede full commercial scale development.

The results of the first phase are shown in the heat maps presented below and in Section 7.9. The results of the second phase, including a breakdown of component costs, are presented in the following tables.

Table 38: Cost of Energy modelling results by zone for a single wind farm, 4 MW WTG, 504 MW wind farm, Gujarat.

Zone	LCOE (INR/ MWh)	Foundation concept	Export infrastructure	DevEx (mINR)	Foundation CapEx (mINR)	Electrical CapEx (mINR)	Turbine CapEx (mINR)	OpEx (per annum) (mINR)	AEP (GWh/annum)
A	2,1481	MONOPILE	220 kV	16,095	25,259	34,752	70,050	4,115	1,013
B	2,1601	MONOPILE	220 kV	15,689	22,346	34,170	70,165	4,066	984
C	2,2357	MONOPILE	132 kV	15,326	26,467	27,137	70,050	4,002	930
D	2,2849	MONOPILE	132 kV	15,475	23,280	31,454	70,165	3,941	913
E	2,3385	MONOPILE	220 kV	16,781	25,455	40,275	70,050	4,251	970
F	2,2257	MONOPILE	132 kV	14,884	21,540	28,267	70,165	3,911	906
G	3,1626	JACKET	132 kV	19,034	46,879	28,681	78,998	4,808	817
H	3,0246	JACKET	132 kV	18,966	47,752	32,019	74,221	4,642	845

Table 39: Cost of Energy modelling results by zone for a single wind farm, 6 MW WTG, 504 MW wind farm, Gujarat.

Zone	LCOE (INR/ MWh)	Foundation concept	Export infrastructure	DevEx (mINR)	Foundation CapEx (mINR)	Electrical CapEx (mINR)	Turbine CapEx (mINR)	OpEx (per annum) (mINR)	AEP (GWh/annum)
A	17,596	MONOPILE	220 kV	15,714	23,939	33,885	69,066	3,497	1,178
B	17,575	MONOPILE	220 kV	15,323	21,186	33,303	69,138	3,480	1,153
C	18,180	MONOPILE	132 kV	15,208	27,335	26,270	69,066	3,470	1,106
D	18,346	MONOPILE	132 kV	15,103	22,069	30,587	69,138	3,477	1,090
E	19,278	MONOPILE	220 kV	16,399	24,124	39,408	69,066	3,529	1,117
F	17,961	MONOPILE	132 kV	14,477	20,045	27,400	69,138	3,477	1,074
G	23,489	JACKET	132 kV	16,850	36,447	27,814	72,096	4,235	969
H	22,801	JACKET	132 kV	17,087	37,029	31,152	70,154	3,836	990

Table 40: Cost of Energy modelling results by zone for a single wind farm, 4 MW WTG, 150 MW wind farm, Gujarat.

Zone	LCOE (INR/ MWh)	Foundation concept	Export infrastructure	DevEx (mINR)	Foundation CapEx (mINR)	Electrical CapEx (mINR)	Turbine CapEx (mINR)	OpEx (per annum) (mINR)	AEP (GWh/annum)
A	20,890	MONOPILE	220 kV	5,727	7,618	14,917	21,126	1,241	345
B	21,004	MONOPILE	220 kV	5,585	6,739	14,582	21,161	1,226	335
C	20,911	MONOPILE	132 kV	5,284	7,982	10,866	21,126	1,207	319
D	21,819	MONOPILE	220 kV	5,456	7,021	13,223	21,161	1,188	314
E	23,283	MONOPILE	220 kV	6,109	7,677	18,044	21,126	1,282	331
F	21,112	MONOPILE	132 kV	5,200	6,496	11,616	21,161	1,180	310
G	29,386	JACKET	132 kV	6,461	14,138	11,818	23,825	1,450	281
H	28,641	JACKET	220 kV	6,513	14,401	13,426	22,384	1,400	288

Table 41: Cost of Energy modelling results by zone for a single wind farm, 6 MW WTG, 150 MW wind farm, Gujarat.

Zone	LCOE (INR/ MWh)	Foundation concept	Export infrastructure	DevEx (mINR)	Foundation CapEx (mINR)	Electrical CapEx (mINR)	Turbine CapEx (mINR)	OpEx (per annum) (mINR)	AEP (GWh/annum)
A	17,531	MONOPILE	220 kV	5,580	7,125	14,755	20,555	1,041	391
B	17,497	MONOPILE	220 kV	5,444	6,305	14,420	20,577	1,036	382
C	17,465	MONOPILE	132 kV	5,215	8,135	10,704	20,555	1,033	368
D	17,960	MONOPILE	220 kV	5,312	6,568	13,060	20,577	1,035	364
E	19,619	MONOPILE	220 kV	5,961	7,180	17,881	20,555	1,050	372
F	17,451	MONOPILE	132 kV	5,047	5,966	11,453	20,577	1,035	357
G	22,476	JACKET	132 kV	5,763	10,847	11,655	21,457	1,260	323
H	22,301	JACKET	220 kV	5,907	11,021	13,264	20,879	1,142	328

7.9 Cost of Energy Heat Maps

Based on the results of COE modelling, heat maps were developed. These maps are shown in the following Figure 26 and Figure

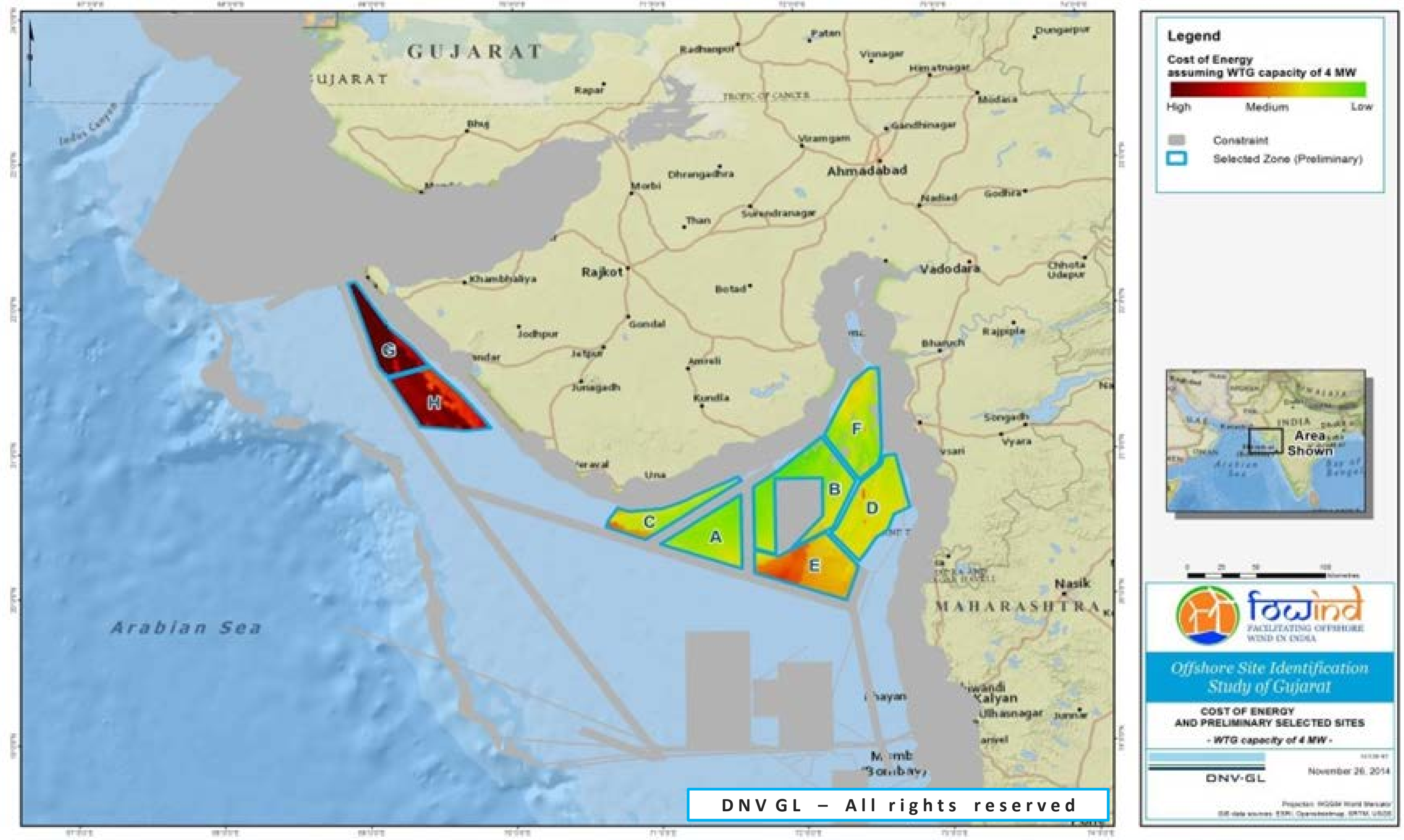


Figure 26: Cost of Energy Heat Map for Gujarat with 4 MW WTGs.

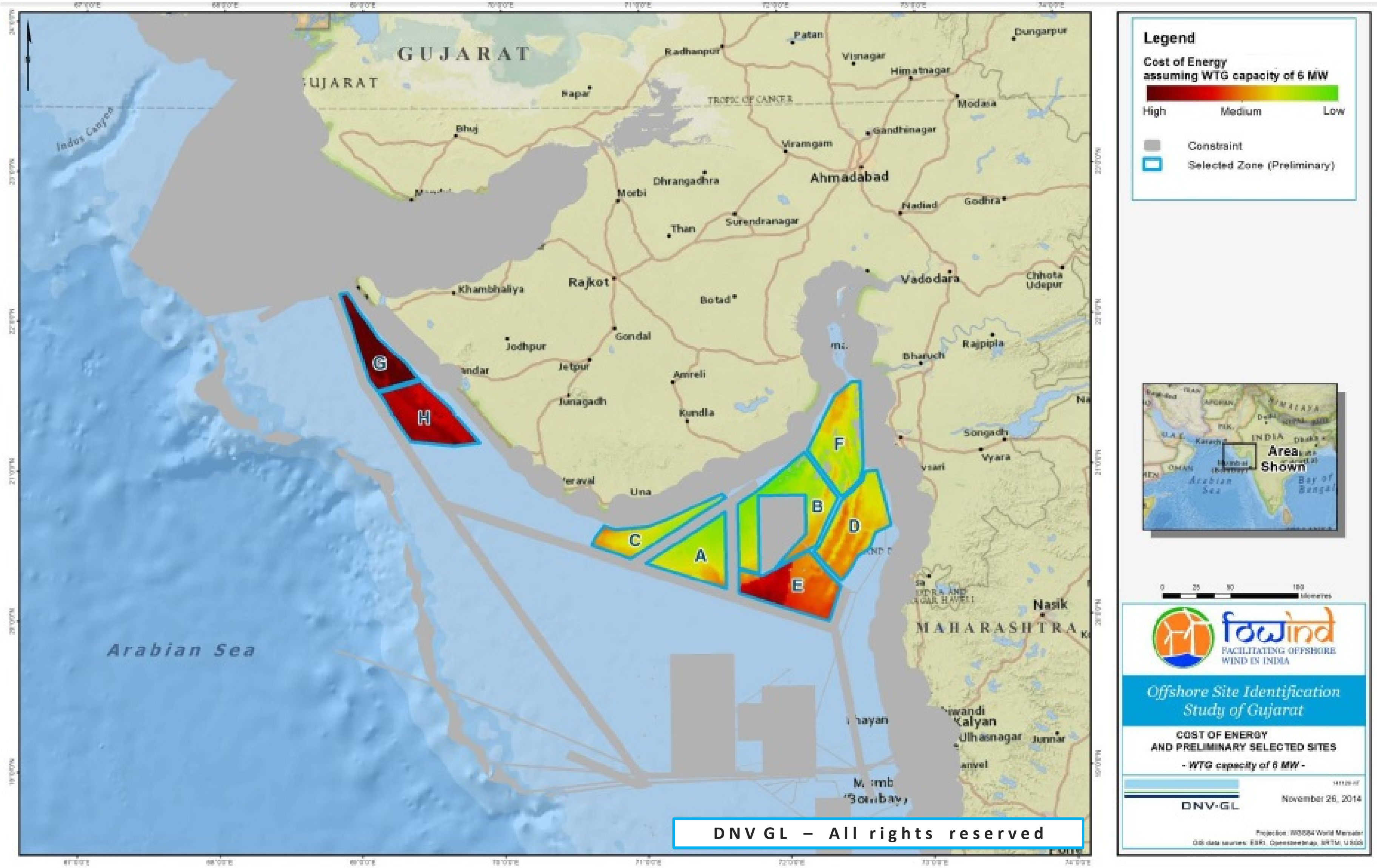


Figure 27: Cost of Energy Heat Map for Gujarat with 6 MW WTGs

7.10 Project cost summary

FOWIND has undertaken high Level Cost of Energy modelling (using DNV GL's in-house COE models) for eight offshore zones for the Indian State of Gujarat. The results of this modelling are presented in Section 7.8 and heat maps in Section 7.9.

The results from the modelling allow the following conclusions to be drawn:

- Zones A and B represent the most economic locations for offshore wind developments in Gujarat with 6 MW WTGs;
- Zones C and F in Gujarat, also present reasonable conditions for the development of offshore wind (Note: High tidal flows in at least Zone F have been identified that may limit installation or may result in increased installation cost);
- Offshore wind developments comprising larger wind turbines are more economic than those comprising smaller turbines. This reflects current development in Europe and the general move to larger turbines.

It should be noted that the above conclusions are primarily related to the deployment of 6 MW WTGs, which represent the lowest LCOE modelled. A similar trend of LCOE across the zones of both regions is broadly followed for 4 MW WTGs as well, with some minor variations primarily due to the impact of reduced wind speeds at particular zones. The comparison between zones across the region is shown in Figure 28.

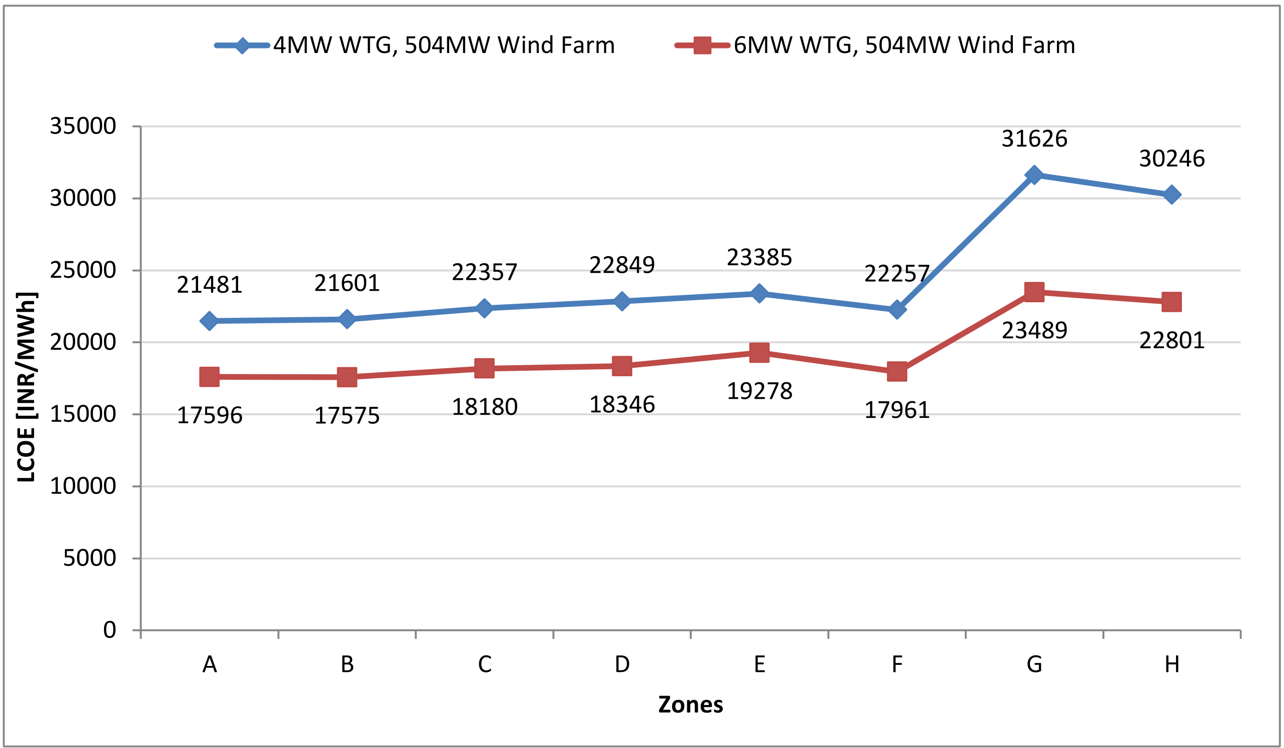


Figure 28: Comparative cost of energy for Gujarat (504MW Wind Farm).

The development of offshore wind energy is affected by a wide range of interconnecting factors. However, the following general principles apply in the assessment of Cost of Energy, and can be borne in mind both in relation to the above results and when considering offshore wind development in general:

- Wind resource is the most significant factor affecting offshore wind LCOE. Sites with a good wind climate generally exhibit a lower LCOE;
- Deeper water increases WTG foundation size and weight, and hence cost; generally, deeper sites are more costly. Shallower water also enables the selection of monopile foundations, which are currently the most economic concept;
- Increasing distance from the grid connection point results in more costly electrical infrastructure, and therefore increased cost of energy. Alternative export infrastructure technology can mitigate this to some extent;
- Onerous metocean conditions increase vessel risk, and hence contribute to both increased construction costs and increased operating costs.

It should also be noted that the cost of energy calculated in this project is significantly higher than that for commercial developments in Europe. The primary driver behind this cost is the local wind resource; mean wind speeds used in the modelling are considerably lower than those exploited in Europe, with a consequent reduction in annual energy production over which the project costs can be distributed.

Due to the high level of uncertainty associated with the constraints data and with the modelling process the FOWIND consortium recommends that the results presented in this study are used solely for pre-feasibility purposes only.

8 HIGH LEVEL TECHNICAL RISK CONSIDERATIONS

8.1 Introduction

When planning offshore wind farm projects, all decisions must be considered regarding potential future actions, although outcomes cannot be foreseen with certainty due to incomplete information. This uncertainty associated with all business activity is defined as risk. The aim of this section is to provide a high level qualitative assessment of the principal risks for the potential offshore wind farm zones identified in Gujarat. It is important to ensure that significant risks are managed and that mitigation measures are identified.

Table 43 undertakes a qualitative assessment of the main risks identified in this report, incorporating potential mitigation measures. It should be noted that all of the risks listed in Table 43 are zone related risks that would generally apply but given the high level information obtained for the Gujarat region to date, the uncertainty is considered high. It should be considered non-exhaustive but nevertheless a starting point for project risk consideration. Table 42 offers an overview of risk levels, categories and actions required. Further investigation will be conducted as part of the FOWIND project.

8.2 High level qualitative assessment of main technical risks

Table 42: Risk Level and Category

Risk Level	Risk category	Action required
Low	Acceptable	Low risk level. No risk mitigations required. Check that no other risks can be eliminated.
Medium	Might be reduced to ALARP	Risk identify that will require mitigation measures. Reduce risks as low as reasonably practical (ALARP); Consider alternative design or construction method; If alternatives are not available, specify precautions to be adopted.
High	Not acceptable	Potential major impact. Mitigation is required. Seek alternative solutions or if alternatives are not available, specify precautions to be adopted

Table 43: Qualitative assessment of main risks and potential mitigation measures.

No #	Issue	Risk	Description	Consequences	Risk level	Mitigation
1	Consenting	Uncertainty of the regulatory regime	There is currently no offshore wind permitting and consenting regime for the EEZ in India. This leads to a number of uncertainties with regards to the consenting schedule and technical requirements for off- and onshore construction.	This uncertainty may cause delays in the approval process and/ or the installation process with financial consequences on the overall project budget.	Medium	A proper defined permitting and consenting process based on suitable regulatory framework forms the basis for any offshore wind development and needs to be setup upfront.
2	Wind resource	Uncertainty of the wind resource assessment	At this stage of the project wind resource assessments are based on mesoscale modelling. This data are generally associated with a relative high uncertainty.	A high uncertainty of the wind resource assessment can have significant financial consequence for the project.	High	It is common practice to conduct a site specific wind potential analysis and energy yield assessment based on long term wind measurements on the proposed offshore wind farm site.
3	Metocean climate (water)	Uncertainty of the wave and current data	For the design and the installation of the offshore wind farm it is important to fully comprehend the oceanographic conditions in the proposed area. In particular high tidal currents have been identified in several areas around river estuaries in the Gujarat region which need to be considered.	This may impact the foundation design, project costs and project timeline.	High	To reduce uncertainty a detailed metocean site condition assessment is recommended.
4	Bathymetry	Uncertainty of the bathymetry assessment	The data gathered during the bathymetry desktop study are associated with a relative high uncertainty.	High uncertainty of the bathymetry data could have significant consequences on the foundation costs.	Medium	After the selection of potential offshore wind farm sites on-site bathymetry surveys are required to be carried out.
5	Geotechnical conditions	There is only limited information on the seabed geology of the Gujarat region available	The results of the conducted desktop study of the geology of the Gujarat region shows that only limited suitable data for planned offshore wind region exist.	Geological data are essential for the design of the WTG and substation foundation. The limited availability of suitable data increases the uncertainty in the design process of the foundation and could have a significant influence on the foundation costs.	High	Detailed geotechnical and geophysical site surveys are to be conducted in a later project stage to reduce the uncertain in the foundation design process.

No #	Issue	Risk	Description	Consequences	Risk level	Mitigation
6	Soil conditions and Jack-up vessels	The soil conditions on site indicate a high level of silting at certain locations	The current desktop study for the proposed offshore wind farm zones shows high level of silt at certain location. Jack up vessels usually required for jacking operations firm soils.	A high level of silt may limit the suitability for jacking operations on site.	Medium	If jack-up vessels are considered as part of the offshore installation concept, a full site specific assessment for the proposed offshore wind farm site is required.
7	Ports and logistics	Uncertainty of the port assessment	The conducted desktop study on suitable construction and O&M ports in the Gujarat region is based on a limited number of available data.	This may impact the pre zone selection for the potential wind farm developments.	Medium	It is recommended to conduct a full port assessment including site visits in a later project stage to reduce uncertainty.
8	Ports and logistics (vessels)	Availability of suitable installation and O&M vessel	So far only a limited number of the offshore wind activities can be observed in the APAC region which leads to a reduced availability of specialist offshore wind installation vessels. The availability of suitable vessels from the oil and gas industry is highly dependent on demand and is subject to high fluctuations.	The general availability of suitable installation vessel can have a significant influence on the overall installation time schedule and budget and may require mobilization of suitable vessels from Europe.	Medium	To ensure that installation capacities are available to acceptable costs it is recommended to start negotiating installation contracts in ample time.
9	Environmental and Social Impact Assessment (ESIA)	Uncertainty on the outcome of the ESIA	Construction activities in breeding and feeding seasons may impact marine life.	The occurrence of migrating birds and marine mammals in the proposed offshore wind farm zones can have significant consequences on the construction schedule and the installation methodology, e.g. piling with noise mitigation measure could be required.	Medium	Piling noise can be reduced with bubble curtains or using vibration technologies instead of hydraulic hammer. The impact on migration of birds and marine mammals can be mitigated by programming construction activities suitably.
10	Health, safety and environment	Health and safety risk	Working in an offshore environment represents an event with significant requirements on man and material. In particular considering that the offshore wind industry is relatively young industry compared to established industries like offshore oil and gas.	Injury to persons, extensive damage to structures and systems and delay to project, pollution of the environment.	Medium	A high safety culture is essential to ensure the project success without having severe incidents. A health, safety and environment management system is to be considered as an important cornerstone of a H&S culture.

No #	Issue	Risk	Description	Consequences	Risk level	Mitigation
11	Electrical design & engineering	Uncertainty of the electrical design	The data gathered during the conducted desktop study are subject to high uncertainty.	The uncertainty of potential grid connection point may cause changes in the electrical design and layout with significant consequences on project costs and the overall project schedule.	Medium	The available information needs to be verified to reduce the existing uncertainties.
12	Turbine Technology	Technology risk	The technology of offshore wind turbines is still immature in case of larger capacities. Hence choosing a large capacity turbine can be risky. Furthermore, wind turbine technology has not been tested in Indian offshore conditions.	Technology related turbine breakdowns can cause a significant reduction of the turbine availability.	Medium	Given the current status of production and commercial experience of large scale offshore wind turbines with 5 MW and above. Turbines with a suitable track record should be chosen to reduce the technology risk.
13	Grid connection	Grid availability	These existing transmission infrastructures may be utilised to cover small scale offshore wind developments in Gujarat, but not for large scale deployment of offshore wind power plants.	Unavailability of adequate grid infrastructure and grid reliability reduces the amount of electricity feeding into the grid.	High	For large scale offshore wind farm projects new or upgraded transmission infrastructure will be required. A sufficient test programme of the grid infrastructure should be simulated in advance to avoid shut downs during operation.
14	Installation	Weather down time	Weather down time needs to be adequately considered in overall project schedule. In particular the impact of the summer monsoon period on the turbine availability has not been thoroughly assessed.	Not considered weather down time could lead to higher lead times and increased project costs.	Medium	It is common praxis within the industry to calculate the weather down time based on statistical weather. However, there is still a risk that the weather down time is above the statistical norm.
15	Installation	Availability of suitable installation equipment	The monopile is one of the preferred WTG foundation designs. The diameter of the monopile designs for up to 30m water depth can exceed 6 m. The size of a hammer required to drive such monopiles are currently not available on the market. Nevertheless such hammers are under development.	The availability of suitable equipment can have a significant influence on the installation time schedule and budget.	Medium	The availability of suitable equipment needs to be considered in the foundation design phase. Installation equipment contracts are to be negotiated right before the start of the installation.

No #	Issue	Risk	Description	Consequences	Risk level	Mitigation
16	CapEx	Uncertainty of CapEx	The project CapEx are estimated based on DNV GL's experience from previous projects and may be subject to significant changes.	The project CapEx can vary significantly from the estimated figures depending on parameters of the final offshore wind location and layout.	Medium	It is recommended to update the CapEx cost model in a later project stage considering the final offshore wind farm layout.
17	OpEx	Uncertainty of OpEx	Considering the available project parameters the OpEx are relatively uncertain and may be subject to significant changes.	The OpEx can vary significantly from the estimated figures depending on the final offshore wind project parameters.	Medium	It is recommended to update the OpEx cost model considering the final layout of the proposed offshore wind farm.
18	DecEx	Uncertainty of decomEx	Based on the current development stage of the offshore wind zones, the decomEx can only be estimates with a high uncertainty.	The decomEx can vary depending on the final installation and decommissioning methodology.	Medium	The decomEx should be included in the financial model as a share of the CapEx. Offshore decommissioning works are assumed to be similar, in cost and effort to the installation work.

9 HIGH LEVEL FINANCIAL FEASIBILITY FOR OFFSHORE WIND

9.1 Introduction

The international offshore wind market is increasingly seeing interest from a wide array of funding agencies using innovative structures. From the pioneering days when the scene was dominated by power producer balance sheet financing, the arena has grown to include over 30 banks with experience in offering financing to the sector – including lending during earlier project stages and absorbing construction risk [57].

This section presents some of the existing financing solutions available in India which might offer assistance to offshore wind farm development. Central and state government renewable energy incentives are touched upon as is the potential sale of carbon credits.

9.2 Mode of finance attainable for offshore wind projects in India

Renewable energy (RE) technologies are witnessing rapid growth in India owing to the major drivers of energy scarcity for a rapidly growing population, rising fossil fuel imports, environmental pollution and concern over climate change. This growth in the RE sector has been facilitated by the Indian Government's commitment towards increasing the share of RE in the grid by up to 15 % by 2020 under its National Action Plan on Climate Change. Several incentives such as feed-in tariffs, generation based incentives (GBIs), accelerated depreciation (AD) and tradable renewable energy certificates (RECs) in addition to Renewable Purchase Obligations (RPO) are available to RE projects. However, several regulatory and bankability challenges exists, such as a high cost of debt (high interest rates), lack of credit worthiness of utilities and non-compliance on RPO and REC mechanism by the utilities. For capital intensive projects such as offshore wind, it is probable that the government will also have to play a major role in ensuring access to finance by providing appropriate incentives.

In India, the bulk of onshore wind and solar PV sector financing has been balance sheet financing, based on the strengths of the developer rather than that of the project itself [58]. Non-recourse financing and limited recourse financing which was largely unavailable in India is now being considered with the advent of independent power producers (IPPs) [59] and non-banking finance companies (NBFCs).

9.2.1 Indian renewable energy financing sources

Debt financing serves a useful purpose in the financing of RE projects in India, as it plays a major role in reducing the cost of capital on a project. Seventy percent of RE projects in India are financed using conventional term loans [60]. In the case of grid-connected renewable energy projects, private financing instruments, such as debt, equity, mezzanine, and partial risk guarantees are being used in India [61]. Equity financing is provided primarily by private equity investors, tax equity investors and strategic investors [60]. This section describes commonly used sources of debt and equity finance in India.

Debt financing:

In India, generally 70 % of project costs are funded through conventional term loans. Domestic banks and non-banking finance companies (NBFCs) are the major sources of debt in India. Some features of the current debt financing scene for RE in India are listed below:

Debt financing for RE projects in India is mostly provided through local currency term loans by public and private financial institutions. The Indian Renewable Energy Development Agency (IREDA) and the Power Finance Corporation (PFC) lead debt financing of RE projects in India. Most loans provided by these institutions are partial or full recourse debts. Private non-banking finance companies (NBFCs) such as L&T Infrastructure Finance and Tata Capital, Mahindra Finance, IDFC, IL&FS and SBI Capital Markets also finance RE projects. Many private NBFCs provide loans on a non-recourse or limited recourse basis without substantial guarantees from the parent company.

Foreign currency loans are provided to wind projects by development banks, export-import (EXIM) banks and international banks. However, all foreign currency loans carry an exchange rate fluctuation risk, although they typically carry lower interest rates.

Support from supply chain: some suppliers extend credit to RE projects for the construction period, limited to the value of the material supplied by them.

Project developers use short-term loans to fund projects during the construction period, and then refinance them with cheaper term loans post commissioning. This is because the construction phase involves higher risk and hence a higher interest rate is charged during this period.

There are several sources of debt financing in India. These sources vary in terms of interest rates, tenure of debt and lending norms. The various sources of debt and their limitations in India are shown in Table 44.

Table 44: Sources of Debt Finance in India

Source: **[60]**, **[62]** and **[58]**

Source of Finance	Expected Interest Rates (%)	Typical Tenure (Years)	Limitations / Challenges	Examples of Institutions
Commercial banks (Public and private)	12-14	8-12	• High rates of interest; • Non-recourse debt (project finance)hardly available; • Low exposure to RE sector due to poor financial health of utilities ; • Banks have sector wise limits(caps), RE comes under power sector cap; • Unfamiliarity with RE sector projects.	• Public sector: State Bank of India (SBI, Bank of Baroda, Canara Bank; • Private Sector: ICICI, Axis Bank, HDFC, IDBI Bank and Yes Bank.
NBFCs	13-15	9-15	<u>Wind</u>: • Higher interest rates than commercial banks; • Non-recourse debt is not easy to avail. <u>Solar</u>: • Lower interest rates than commercial banks offer; • Although still difficult to obtain non-recourse project finance, it is easier to obtain it from NBFC than from commercial banks.	L&T Infrastructure Finance, Tata Capital.

Source of Finance	Expected Interest Rates (%)	Typical Tenure (Years)	Limitations / Challenges	Examples of Institutions
Government backed NBFCs	12-14	10	• As of March 2012, only 15% of RE projects have been financed by IREDA and PFC which lead debt financing in this sector.	IREDA, Power Finance Corporation(PFC), Rural Electrification Corporation(REC), India Infrastructure Finance Company Ltd.
Infrastructure funds	13-15	9-15	• Typically higher risk profile and higher cost of debt; • Also provide equity.	Infrastructure Development Finance Company (IDFC), SBI Macquarie, IL&FS.
External Commercial Borrowings	11.8 approx. (LIBOR rate after accounting for currency hedging)	9-18	• Foreign exchange risks; • Hedging costs add 3%-6% to costs; • Tighter ECB norms by RBI can deter some lenders.	US EXIM, China EXIM, Japan Bank for International Cooperation (JBIC), Asian Development Bank (ADB), International Finance Corporation (IFC).
Construction/ Bridge/ Mezzanine Finance	Higher rates than above listed sources.	variable tenure (short-long term)	• Higher rates of interest than other debt sources; • Mezzanine investment by foreign players may attract some restrictions under the ECB norms of RBI.	NBFCs and Commercial Banks.
Post construction finance	Lower rates available for post-construction refinancing	Longterm tenure	• Easier to obtain.	All as mentioned above.
Development banks and Export Credit Agencies (ECA)	Lower rates offered than NBFCs and commercial banks	Long term	• Longer application process required; • With certain conditions attached (ie less mature technology or equipment with defined country origin).	Ex ADB, IFC/World Bank, US Exim bank, Green Investment Bank, European Investment Bank, European Bank for Reconstruction and Development and Global Environment Facility.
Green Bonds	N/A	3 - 10	• Are typically being used for operational projects only.	World Bank, IFC, IREDA< Greenko Plc (hydro and wind assets) issued on Singapore stock exchange .

Equity financing:

In India about 30-40% of the total project cost is financed by equity. Strategic investors, venture capital, private equity and tax equity investors are the key providers of equity to RE projects; most of them primarily focus on large scale wind and solar projects [60]. In India, the return on equity ranges from 16-20% for RE projects [63] [64] and depends on factors such as the size of the project, the sponsor's background, technological risk, the stage of maturity, geographic and policy risks. Private equity funds have been actively investing in renewable projects since 2008. Key players and challenges to equity financing in India are shown in Table 45. Table 56 in Appendix 5 shows international equity players.

Table 45: Key Players and Challenges in Equity Financing of RE Projects in India

Source: **[60]**.

Key players in Equity Financing	Challenges to Equity Financing in India
• Green Infra Private Ltd (owned by IDFC Private Equity); • Renew Power Ventures Private Ltd (owned by Goldman Sachs Private Equity); • Continuum Wind Energy (majority owned by Morgan Stanley Infrastructure Partners); • Nereus Capital; • IL&FS Financial Services; • Global Environment Fund.	• Certain investor groups are restricted towards less risky technologies (e.g. pension funds or insurances) or states with favourable policies; Higher rates (16%-20% or above) are required. The debt/equity spread for solar is smaller than for wind; • Tenure depends on the investor profile, while IPPs hold assets longterm, infrastructure funds or specialised RE funds target 5-7 year tenures; • Equity is more easily available than debt.

More recent financial innovations, such as Yieldco's (recent examples for solar are Sunedison Terraform and Foresight), are providing the equity markets with cheap equity capital (3-7% with lower ranges in the US and higher in the UK). Sunedison's Emerging Market YieldCo, with a pipeline of operational projects is expected to be listed mid 2015 in the US. Some of this capital is expected to be used for Indian Projects. To date Yieldco's focus has been on solar PV, and has not included offshore wind projects yet.

Lease financing and third party ownership:

This is a commercial arrangement between a financial institution and the project developer, where the former purchases the generating equipment and other components and leases them to the project developer. In India, the leasing industry is dominated by NBFCs.

Partial risk guarantee facilities:

It assumes the lenders' default risk on part of the amount of debt provided to the project. They are used to encourage lending to projects that otherwise would not have been funded by financial institutions due to various reasons, such as the use of new technologies, counterparty risk, or a lack of understanding among lenders regarding a new sector. Asian Development Bank (ADB), World Bank and EXIM/ECA bank are the major players.

The Indian mode of offshore wind project financing will likely follow the European trend. Large public sectors such as the National Thermal Power Corporation, the Oil and Natural Gas Corporation and Power grid etc. could play a major role initially[4]. At first the projects will be supported by the government as the technology will be new in the country and involve various risks (construction risk, technology risk, operations and maintenance risk, wind availability risk, etc). IREDA and PFC, the major government agencies, may initially give financial support. Similar to trends in more mature offshore wind markets, for example in Europe, the role of private finance will increase as the offshore wind power market matures.

[4] Such a consortium has materialised under the ambit of the MNRE with a mandate to set up a 100MW pilot offshore wind power project in Gujarat [157].

9.3 Incentives for renewable energy in India

Several incentives are given to RE projects in India at the central and state level. Key incentives have been described in Table 46 [1].

The Indian Government gives incentives to states promoting RE. For example, grants have been paid as an incentive to states that increase the share of electricity generated from renewable [1]. A comprehensive list of RE enabling measures by the central government can be found in the FOWIND Inception Report (annexure 5), which is available on the FOWIND website [1].

Table 46: Key Incentives for Promotion of Renewable Energy in India.
Source: [60]

Incentive	Details	Type
Feed in tariff (FiT)	Utilities procure electricity at predetermined tariffs. These tariffs are decided by State Electricity Regulatory Commissions; Capital costs, operating costs, capacity utilisation factor, cost of debt and equity are considered for calculating the FiT.	State
Renewable Purchase Obligation (RPO)	Electricity Act 2003, has mandated all state utilities, captive power companies and open access consumers to procure a part of electricity from renewables, known as RPO; RPO can be fulfilled through direct purchase via bilateral contracts or tradable Renewable Energy Certificates (REC) mechanism which can further generate revenue for RE projects.	State
Renewable Energy Certificate (REC)	Launched in 2010, REC is a tradable certificate where one certificate is equal to 1 MWh of renewable energy generated; Purchased by state utilities, open access and captive consumers to fulfil the RPO; Floor price for Non Solar REC and Solar REC is INR 1,500/REC and INR 9,300/REC respectively; Forbearance price for Non Solar REC and Solar REC is INR 3,300/REC and INR 13,400/REC respectively.	Central
Accelerated Depreciation (AD)	Grid connected solar energy projects can claim accelerated depreciation of 80% in the first year of operation. This used to be the case for wind until end of Q1 2013; it has since been reduced to 15 %.	Central
Generation Based Incentive (GBI)	A GBI of INR 0.5/kWh for every unit generated is given to wind generators for at least four years and up to ten years;	Central

Incentive	Details	Type
	The maximum amount that can be availed per year is INR 2.5 million per MW, and the maximum amount that can be availed in 10 years is INR 10 million per MW; A project can claim either AD or GBI, but not both.	
Wheeling and Banking Provisions	Wheeling charges are the charges paid to a distribution utility by generators and consumers for using their network for electricity transmission. Renewable generators are given concession by the state utilities for using their network; Banking provision is offered by some states to renewable generators who can bank excess energy (2% in Karnataka and 5% in Tamil Nadu) for future use.	State
State Nodal Agencies (SNA) project facilitation	SNAs facilitate project development right from resource assessment to the final commissioning; SNAs undertakes resource assessment studies; SNA supports developers by facilitating development of infrastructure at identified sites and also verifies the legal statutory clearances sought by developers from different departments.	State
Capital subsidy	Maharashtra has the provision for capital subsidy to the extent of 11% for wind energy projects set up by the cooperative sector. The State also has provision for capital for wind power projects under Green Cess Fund (GCF); Rajasthan provides soft loans equal to 1/3 of capital cost to developer at low interest rates.	State
VAT exemption	Gujarat and Tamil Nadu offer 5% VAT for all renewable components [65] and [66].	State
Investment in infrastructure	Gujarat has created a solar energy park by providing the following financial incentives and investment in infrastructure [67]: Provision of 2,024 hectare of land for establishing the complete 'solar ecosystem'; Single window facility to developers for infrastructure facilities like land, water, power evacuation system and road; Many other states are in process to set up similar parks for large scale solar power projects.	State

Incentive	Details	Type
Exemption on electricity duty	RE project is exempted from electricity duty by state governments.	State
Other fiscal incentives	Import duty concession on wind turbine components; Excise duty relief; Income tax holidays for wind power projects - 100% Foreign direct investment (FDI) allowed; Weighted income tax deduction for in-house R&D activities; wind turbine manufacturers can claim 200% of costs incurred.	Central

9.3.1 Central government wind energy incentives

Onshore wind energy has been developed in India since the 1990s and has since become the 5th largest wind energy market in the world (22 GW installed capacity as of September 2014). A number of central government incentives are listed below:

- **Viability Gap Funding (VGF)**: VGF is a scheme by the Government of India to fund infrastructure projects taken under the Public Private Partnership (PPP) route. VGF is provided as a grant at the stage of project construction. The grant is equal to the lowest bid for VGF, subject to maximum of 20% of project cost. The VGF can be further extended by 20% (i.e. 40% of project cost) by approval from the government. VGF requires an approval from Empowered Committee (Committee under the Chairmanship of Secretary (Economic Affairs)) and including Secretary Planning Commission, Secretary (Expenditure) and Secretary (MNRE) and Finance Ministry for projects requiring funds more than INR 2,000 million [68].
- **National Clean Energy Fund (NCEF)**: NCEF was announced in the fiscal year (FY) 2010-11 by the Government of India for funding research and innovative projects in clean energy technology. It could be used to fund demonstration offshore wind projects. Amount in the NCEF corpus was INR 101,270 million as of March 2014 with a potential addition of INR 68,000 million during FY 2014-15 [69].
- **Sectoral Caps**: Not only Indian commercial banks have sectoral caps for lending to the power sector, but also India's Central Bank. Current lending norms by the Reserve Bank of India for the power sector are limited to 15% for single borrower and 40% for consortium [70]. Lending to the renewable energy sector is also covered under this cap
- **Guaranteed electricity offtake and preferential grid access**: The distribution utilities in India are cash strapped with bad payment histories and are often not considered bankable offtakers. Guaranteed offtake of electricity as well as preferential grid access will be required to make offshore wind projects feasible in India. Power from offshore wind projects can potentially be bundled with cheaper sources and sold to the utility at average prices. Similar approach was adopted for solar PV power projects under the Jawaharlal Nehru National Solar Mission.
- **Government backed Green Bonds**: IREDA plans to raise INR 15,000 million in FY 2015-16 by issuing 20 year tax free green bonds to finance clean energy development [71]. Proceeds from the sale can be used to fund offshore projects; alternatively bonds with higher returns for offshore wind projects can be issued.

- **Tax efficient trusts**: Trusts and Master Limited partnerships have been successfully used in some parts of world (i.e. US) to attract investments for specific classes of assets. They provide tax benefits, better cash utilisation and management of project assets [60].
- **Renewable Energy Certificates (REC)**: The current Average Power Purchase Cost in Gujarat is INR 3.65 per kWh. Offshore wind RECs are initially expected to be higher than this value. Exact values are yet to be defined by the Indian government.

9.3.2 Incentives for wind energy in Gujarat

The Gujarat Government encourages wind energy in the state and with over 3000 MW of installed capacity. Gujarat is the second largest wind energy producing state in India. Under the Wind Power Policy-2013 [72], wind turbines installed and commissioned up to the end of March 2016 in Gujarat are eligible to the following (amongst other) incentives for a period of 25 years:

- Wheeling of electricity: allowed on payment of transmission charges, otherwise applicable to normal Open Access Consumer and transmission and wheeling losses @ 10% of the energy fed to the grid. The above loss is to be shared between the transmission and distribution licensee in the ratio of 4:6. Rules vary depending on production capacity, captive consumption or third party sales and/or multiple locations wheeling (see [72] for more details).
- Electricity Duty exemption: electricity generated from wind turbines is exempt to duty.
- Preferential tariff sale: electricity generated from the WTGs commissioned from 8.08.2012, may be sold to any state Distribution Licensee at a rate of INR 4.15 per kWh. The requisite power purchase agreement (PPA) shall be done between the power procurer and the eligible unit.
- Banking: settlement to be done on monthly basis and surplus energy to be considered as sold to utility at 85% of prevailing tariff rate.
- Buy-back: INR 3.50/ kWh for 20 years [73].

9.4 Consumer unit Cost of Energy

Electricity prices are a crucial factor in deciding the bankability of power projects. Electricity prices in India have grown at a compound annual growth rate of 7.98% since FY 2009-10. The average tariff per unit for electricity sold during last five years is shown in Figure 29.

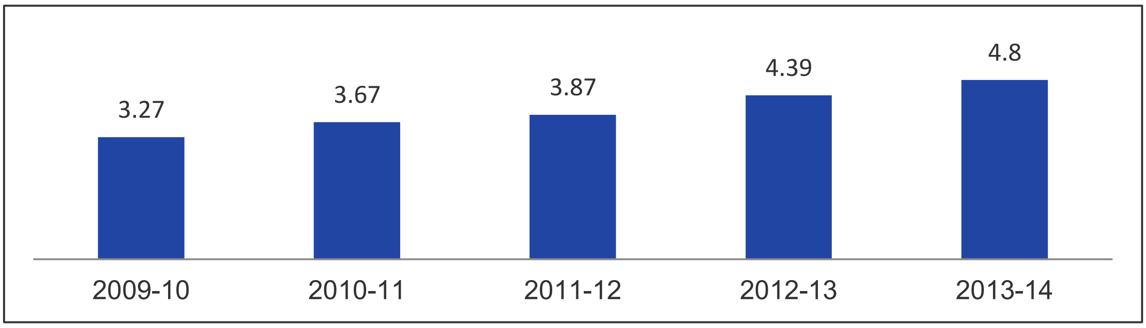


Figure 29: Average Power Tariffs (INR/kWh) in India
Source: **[74]**

9.4.1 Electricity prices in Gujarat

Gujarat Urja Vikas Nigam Ltd (GUVNL) is the single bulk buyer of electricity as well as the bulk supplier to the state distribution companies. There are four main electricity utility companies in Gujarat: DGVCL (Dakshin Gujarat Vij Company Ltd); MGVCL (Madhya Gujarat Voj Compant Ltd); UGVCL (Uttter Gujarat

Vij Company Ltd); PGVCL (Paschim Gujarat Vij Company Ltd); their power purchase cost varies between 2.97 to 4.71 INR/kWh [75].

9.5 Sale from carbon credits generated

The Clean Development Mechanism (CDM) was designed to help developed countries fulfil their commitments in reducing emissions, and to assist in achieving sustainable development. CDM allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2. These CER credits can be traded and sold, enabling industrialised countries to meet a part of their emission reduction targets under the Kyoto Protocol [76]. The actual quantity of CO_2 emissions avoided per MW of offshore wind capacity installed is dependent on a number of factors including wind resource, plant performance, etc. The power produced from a 100 MW offshore wind power project could reduce approximately 301,387 tCO_2[5] in a year. These emission reductions can be traded on the international market at their current market price. However, the market price of CER credits has been highly volatile – the CER price was €20 tCO_2 in 2008 (phase II of Kyoto Protocol) and has plummeted to €0.4 in 2013 (phase III of Kyoto Protocol) with a rather weak outlook. The carbon finance associated with the trading of the CER credits can potentially improve the returns of the project and make it more financially viable if the carbon markets improve.

9.6 Positive impact on local industries that are able to support the offshore wind energy industry

This section deals with the high level financial impact of an offshore wind project on local industries in the region. The impact will depend upon the existing infrastructure, supportive industries and skilled labour in the region. The industrial development concepts that may be applicable for increasing the financial feasibility of an offshore wind project include:

- Cluster development of relevant industries can provide balance of plant components in the region;
- Promotion of local industry networks is advised where possible to reduce transportation and storage requirements and ultimately minimise costs;
- Improving coastal infrastructure to meet logistical demands leads to new opportunities and job creation – a benefit to local communities who effectively bear the brunt of local offshore development.

Creation of an indigenous offshore wind manufacturing capacity will provide positive growth and development for the linked supply chains. The sectors that may play major roles are described in Table 47.

5 Calculated based on net plant load factor of 35% with an emission factor of 0.983 tCO2/MWh (Southern grid in India)

Table 47: Sectors that may Promote Development in the Offshore Wind Sector.

Sector	Supportive Development	Remarks
Ports & shipping sectors	Port and port based industries, ship building.	• For trade and storage activities; • Movement of wind turbine assemblies; • Travel/logistics of manpower and materials to and from the offshore wind farm sites and onshore base;
Manufacturing	Engineering, engineering ancillaries, construction goods and materials, electrical and electronics equipment, Information Technology Enabled Services (ITES) etc.	• To fulfil requirements of electrical and other goods/ machines relevant to the sector; • Creating local market networks; • Facilitate development of local industries for inter-sectorial growth (industrial symbiosis); • Reduce distance/time of travel/transport.
Service sector	Telecommunications, basic infrastructure and services, amenities for the residents	• Base provision for workforce.

Gujarat has witnessed a noticeable growth in its industrial sectors in the last two decades. In addition, it has succeeded in widening its industrial base. Coastal areas have witnessed establishment of large industries as well as ancillaries units. This growth has largely been in the engineering sector. Some of Gujarat's key special economic zones (SEZs) are mentioned below.

Kandla SEZ in the district of Kachchh is the largest operational SEZ promoted by the Central Government. In the same region, Mundra SEZ supports a huge industrial investment with the largest port facility in the State. SUR SEZ, located in southern Gujarat (Surat), is a functional multi-product SEZ. Apart from these SEZs, there are many other large operational industrial bases and special investment regions (SIRs) in Gujarat. Table 48 shows the general locations of notified SIRs and the type of industries proposed within them.

As the zones identified for the potential development of offshore wind are located near the coast of Saurashtra and the Gulf of Khambhat, the ports and industries in the Saurashtra region and South Gujarat region are considered to be of most importance.

Table 48: Location of SIRs and Type of Industries Proposed.

Source: **[77]**

Gulf of Kutch	
Anjar, Kachchh	Port & port based industries, mineral & agro based and engineering.
Navlakhi, Rajkot	Ceramic, engineering & automobiles, food processing, electronics, textile, chemical & petrochemicals.
Santalpur (located in North Gujarat)	Agro based, solar power, logistics.
Saurashtra Region	
Pipavav, Bhavnagar	Logistics based industries, pre-cast structures and textile-only spinning.
Simar, Junagadh	Auto & auto components, heavy engineering, electronics engineering, plastics and agri & pharma biotechnology.
Okha, Jamnagar	General manufacturing, pharmaceutical, CRO, biotechnology & biopharma, auto & auto ancillaries, mineral based and tourism.
Sanand-Viramgam	General manufacturing, pharmaceutical, CRO, biotechnology & biopharma, auto & auto Ancillaries, mineral based industries and tourism.
Gulf of Khambhat	
Aliyabet	Entertainment, aquaculture and marine engineering.
Dholera (near Ahmedabad)	IT/ITES, light manufacturing, and engineering.
Halol-Savli (near Vadodara)	Engineering, automobile ancillaries, engineering plastics, electrical and electronics.
PCPIR, Dahej	Related to petroleum & petro-chemicals.
Hazira, Surat	Chemical & petrochemical industry, port & port based industries and heavy engineering.
Changodhar (near Ahmedabad)	Agro based, steel & metal, plastic, pharmaceutical and oil & gas.

Apart from the port and port based SIRs and SEZs, a number of wind turbine manufactures are located in Gujarat. The spread and location of these units is shown in Table 49. Mostly, these units are located in Ahmedabad, Vadodara, Surat, Jamnagar and Bhuj.

Table 49: Locations of Wind Turbine Components Manufacturers in Gujarat

Location	Name of Manufacturer	Component Manufactured
Jamnagar	Wind World India	Tower
Gandhidham	Suzlon Energy Ltd	
Ahmedabad	Inox Wind	
Vadodara	Windar	
Bharuch	Fedders Llyod Corp	
Silvassa	Global Wind Power	
Bhuj	Suzlon Energy Ltd	Blade
Ahmedabad	Inox Wind	
Vadodara	Kemrock	
	Gamesa India	

Location	Name of Manufacturer	Component Manufactured
Daman	Wind World India	
	Suzlon Energy Ltd	
Ahmedabad	Elecon Engineering	Gearbox
Vadodara	ABB India	Generator
	Jyoti Ltd	
Daman	Wind World India	
Ahmedabad	Patel Alloy	Rotor Hub
	SKF	Bearings
Vadodara	SE Forge (Forging and machining)	Shaft
	FAG	Bearings
Surat	L&T (Forging)	Shaft

Considering that the location of the eight selected zones are in the Gulf of Khambhat and Saurashtra coast, manufacturing units in Ahmedabad, Vadodara and Surat may play an important role for future development of manufacturing bases for offshore wind power.

9.7 Summary and recommendations

Offshore wind is a cost intensive source of energy; and whilst, internationally, work is underway to achieve significant cost reductions [24] [78], an innovative approach of financing is needed for its deployment in Indian waters. A number of high level recommendations are offered below from the information covered in this chapter. For a more comprehensive look at offshore wind policy, please refer to FOWIND's Offshore Wind Policy and Market Assessment – a Global Outlook report [79].

- Fiscal mechanisms can be adopted to ensure commercial deployment of offshore wind power projects in India. These could include support in the form of grants from the government, funding by multilateral institutions, power purchase agreements, debt syndication etc;
- Industry specific sectoral caps may be introduced as offshore wind is capital intensive;
- Guaranteed offtake of electricity and preferential grid access is likely to be required to make offshore wind projects feasible;
- Reverse bidding: an auction approach to power procurement wherein the bidder with the lowest bid (after compliance to the minimum stipulated conditions) signs non-negotiable contracts with the power utilities. This approach has resulted in low prices for solar projects in India. A similar approach can be adopted for offshore wind projects;
- Tax efficient trusts could potentially be used to manage offshore wind farm assets;
- Pooling of wind farm assets: Typically, the debt repayment for a wind farm is done only from a specific project's cash flow. CLP India (wind IPP) entered into an agreement with a group of lenders; Standard Chartered, IDBI and IDFC, to create a common revenue pool from its wind farms for servicing debt. This helped CLP in accelerating its expansion [58]. A similar approach can be adopted by offshore wind developers in the future; and
- Renewable energy certificates for offshore wind will need defining by the Indian Government.

Through careful consideration of lessons learnt from national onshore wind and international offshore wind experiences, India can seek to instigate a hybrid incentive system that incorporates the best aspects of both.

10 ENVIRONMENTAL AND SOCIAL IMPACT

10.1 Introduction

This section briefly discusses the potential impacts, regulatory mechanisms and protocols for environmental clearances. A high level predication of environmental and social impacts is offered for the identified zones in the State of Gujarat.

Although India's offshore wind sector is still in its infancy, international experience from environmental and social impacts may be applied from offshore wind specifically and also other offshore industries (oil and gas, shipping etc.). In addition, international experience in the offshore wind industry relating to Environmental Impact Assessment (EIA), which is not as of yet mandatory in India, may provide important guidelines to minimise the impact of offshore wind projects on the environment and society.

10.2 The purpose of Environmental and Social Impact Assessments

Development of an offshore wind power project involves a considerable number of activities, onshore as well as offshore. A number of these activities may impact local stakeholders, terrestrial wildlife, marine life and the environment. Any development which poses risks to the environment or stakeholders needs to undergo a detailed process of impact assessment describing the type and scale of impacts at and around the project site. Environmental and social impact assessment (ESIA) is a process by which information about the environmental and social effects of a proposed development is collected, evaluated and presented to facilitate consultation and to enable decision makers to take account of these effects (beneficial and adverse) when determining whether or not a project should proceed [80]. Typically the process will involve a high level screening phase to provide an overview of the local surroundings. Following this a more detailed scoping phase will take place. During the scoping phase a number of bodies are usually consulted, these typically include: environment and transport agencies, community engagement officers, environmental health officers and wildlife trusts (to name a few). The scoping phase will identify key issues that will be investigated in greater detail during the ESIA.

Environmental regulatory mechanisms in India do not currently have a mandate for onshore wind projects to conduct an ESIA, although some developers will undertake them as part of their due diligence. Wind power is categorised as 'green' by almost all state pollution boards, a tag which ensures that these projects are rarely scrutinised [80]. Offshore wind power projects, due to their inherent on- and offshore requirements deliver a further set of potential impacts and may be subject to specific regulations relating to the marine environment. Broadly speaking, ESIA in offshore wind projects is necessary to analyse (and mitigate if required) the following impacts:

- Impact of noise and vibrations on marine life (particularly marine mammals) and birds (especially protected species) and habitat;
- Water pollution (suspended sediment, hazardous material - oil, diesel, drilling lubricants etc.) during construction, operation and maintenance and decommissioning;
- Loss of habitat, breeding and feeding grounds;
- Effect on fisheries and fishing communities;
- Impact on sites of archaeological significance or important sites of cultural heritage;
- All environmental and social parameters which may be impacted due to development of offshore wind farms and related physical infrastructure on land such as ports, production facilities and transmission networks.

These impacts are a general description of the possible effects. Impacts highly depend on the site and scale of the project. Monitoring will usually focus on seabed morphology, species composition (population dynamics, distribution and abundance), habitat types and characteristics, physical and chemical features (waves, currents, sediment transport, salinity and temperature etc.).

Consideration should also be given to any potential effects on shipping lanes (rerouting requirements); effects on terrestrial traffic and transportation (requirements for abnormal/large loads and road safety); effect on military and civil aviation as well as helicopter operations for oil and gas, search and rescue etc. (maximum blade tip height in relation to airport approach requirements); effects on telecommunications and electricity cables, pipelines, coastal tourism and recreation, marine disposal sites and potential effects on future marine aggregate extraction and port developments. Potential interference with radar needs to be carefully assessed particularly for scenarios of reduced visibility when navigation relies almost entirely on radar. Account must be taken of unexploded ordnance [81].

10.3 International experience

10.3.1 Environmental monitoring studies

Internationally, in order to ascertain the impact of offshore wind power project activities, a number of studies are carried out. These deal with benthic fauna and vegetation, fish, marine mammals, birds, as well as sociological and economic aspects and views towards wind farms.

Below is a brief summary of the studies conducted by Germany and Denmark during their environmental monitoring stages [82]:

1. **Measurement of Noise Emission**: Monitoring of noise levels was conducted during construction and operation to understand its effect on marine life. Its impact is specific to tide and weather conditions as the influence of noise and its propagation is highly dependent on meteorological and environmental parameters.
2. **Movement Identification of Migratory Birds and Marine Species**: The study was conducted to assess the reaction of migratory birds to the rotation of wind turbines.
3. **Impacts on Geology and Oceanography**: The study was conducted to assess and analyse the interactions between offshore structures and the marine environment. This study focused on assessing and characterising the impacts of dynamic sediment processes on geotechnical properties and benthic organisms of the upper seabed.
4. **Socio-Environmental Impact Studies**: These studies were conducted to assess the impact of offshore wind power projects on tourism and local industries and their acceptance in local communities. These studies also suggested measures to avoid future conflicts between stakeholders.

10.3.2 Identified environmental impacts

Offshore wind power projects have the potential to impact marine fauna, flora and the human communities that rely on them or live in the project's locality. These impacts may have effects on the migration, habitation and survival of endemic species and local dwellers. Table 50 summarises the impact of the Horns Rev and Nysted offshore wind power projects in Denmark, as reported by the Danish Energy Authority [83]. Further details of effects and their mitigation measures at a basic level can be found in Appendix 5.

Table 50: Impacts of Offshore Wind Development in Denmark.
Source: [83].

Fauna and vegetation	With time, wind turbine foundations and scour protection may act as artificial reefs for benthic and hard bottom communities. The abundance of species and biomass may increase due to this. Monocultures of common mussels have developed at the turbine structures, due to low salinity and a lack of predators.
Fish	Due to artificial habitat creation, there is a positive effect on fish communities due to development of artificial reefs. There is no linkage between the strength of the electromagnetic field and the migration of selected fish species.
Marine mammals	During construction there can be impacts on coastal species which may recover at different rates during the operational phase (post construction).
Birds	Birds generally show avoidance responses to the wind farms. Some species are displaced from former feeding areas. Collisions with wind turbines have been low.
Public	There may be issues of visual intrusion when near coastline.

10.4 High level prediction of environmental impacts in Gujarat

The Gulf of Khambhat and Saurashtra coastline can be broadly categorised into three sub-regions:

a) The Saurashtra district's coastal boundaries;

b) The Khambhat district coast and;

c) The South Gujarat coast.

A considerable area within the southern coast of the Gulf of Kutch is declared as a marine national park and sanctuary, designated to protect the coral reefs in the region. The towns of Okhamandal, Kalyanpur, Khambalia, Lalpur, Jamnagar and Jodia within the district of Jamnagar constitute the southern boundary of the marine national park and sanctuary [84].

It has not been possible to assess all the environmental constraints at this time. At this stage, focus was given to spread and density of mangroves and corals along the Gujarat coastline. Long-term, a full ESIA is required to assess the type and scale of impacts that may occur. The available information indicates a density of mangroves in the Gulf of Khambhat and sparse density along the Saurashtra coast, although quantification of mangroves and corals has not been considered at this stage. Section 10.4.1 offers a brief description on the spread and density of mangroves and corals in the region.

10.4.1 Coral reef and mangrove

The Gulf of Kutch region is rich in corals and mangroves and is also designated as one of the four major areas of coral reefs in India. The density of the mangrove is higher in this region in comparison with the Saurashtra coast and the Gulf of Khambhat. The marine park off the coast of Okha supports a considerable biodiversity of mangroves and other marine life. Figure 30 shows the known coral reef areas located within the Gulf of Kutch.

Preliminary analysis was conducted in areas of the Gulf of Khambhat where patches of mangroves were apparent in the estuaries. The entire coastal stretch between Bhavnagar and Umargam (most southerly point in Gujarat), contains mangroves. Mangroves are sparse along the Saurashtra coast and comparatively more common on the opposite coastline i.e. the south Gujarat coastal belt. However, with estuaries being favourable ecosystems for mangroves, it is plausible that the Saurashtra coast, which also has a number of estuaries, has a similar mangrove density to the Gulf of Khambhat. In general, the density of mangroves along the Saurashtra coastline is lower than in the Gulf of Khambhat.

The occurrence of mangrove across the Bhavnagar coastal region is sparse in comparison to the estuaries near the South Gujarat coast. However, since mangrove grow in the intersection of land and sea and up to the intertidal zone only, offshore wind farm siting may not directly influence it. Nevertheless, for the purposes of installation, cable lying and onshore activities in these regions, considerations should be made during project development.

A considerable area within the southern coast of the Gulf of Kutch is declared as a marine national park and sanctuary, meant to protect the coral reefs in the region. Within the constraint analysis for this pre-feasibility study, environmentally protected areas with known coral reefs and mangroves were excluded from the study and a 10 km buffer zone was applied.

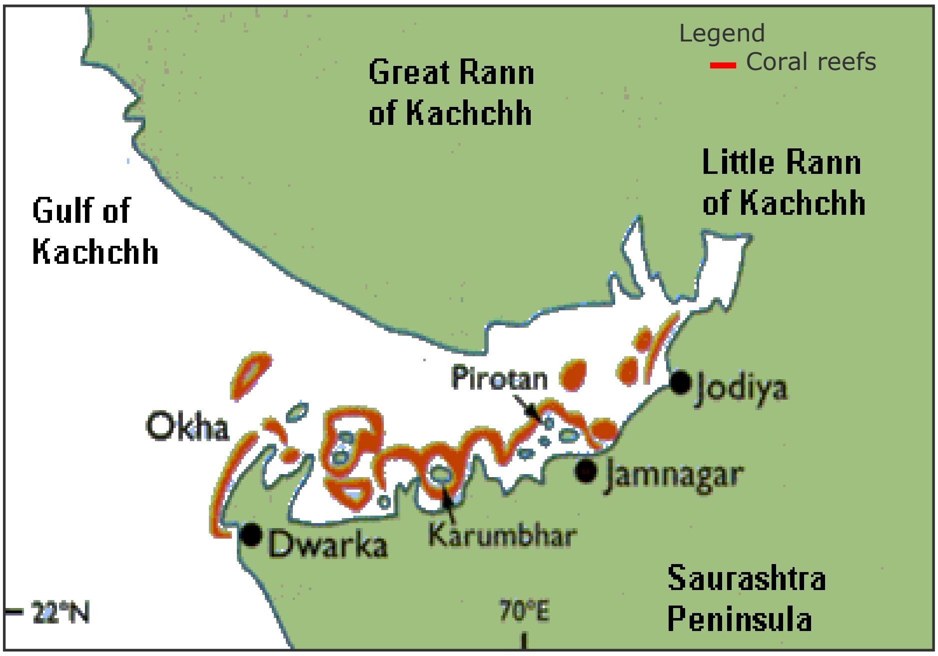


Figure 30: Coral Reefs in Kutch.
Source: **[85]**

10.4.2 Other living organisms

Apart from corals and mangroves, other living organisms may also be impacted due to development of offshore wind in Gujarat. The estuaries of South Gujarat which meet the Gulf of Khambhat are feeding grounds for whale sharks, and Dugongs are found along the Gujarat coastline. Both species are listed in Schedule I of the Wildlife Protection Act -1972 [86]. The coast of Saurashtra acts as a hatching ground for turtles [87]. The region from the Jamnagar coast to Okha supports sparse corals and is of archaeological significance (Dwarka city). Detailed analysis of each zone is needed to clarify the likely impacts on all present species.

10.5 High level analysis of social impacts in Gujarat

The social well-being is assessed by the contribution of project activity to improvement in living standards of the local community. Offshore wind farms will contribute to the local economy by generating employment, reducing social disparity and improving basic amenities. Several social implications are mentioned below:

1) **Cleaner power:** Electricity generated by wind power is regarded as sustainable energy because no environmentally harmful gases like CO_2, NOx or SOx are emitted during the generation of electricity. This will reduce India's greenhouse gas emissions (helping to mitigate the impact on climate change) and contribute to future renewable energy targets. The power produced from a 100 MW wind power project will reduce 301,387 t CO_2[6] annually based on the grid emission factor of 0.983 t CO_2/MWh [88] (CEA database, version 9.0 [89]).

2) **Development/improvement of infrastructure:** In the case of onshore wind projects the related activity also improves local infrastructure such as the connectivity of the area through the construction of roads to the site which will benefit nearby villagers. To a lesser degree this should be applicable for offshore wind developments. However less road infrastructure is typically required for offshore projects due to the larger size of wind turbines and substructure components. Due to these large dimensions road haulage is often precluded in offshore wind in favour of developing local port infrastructure and transporting by sea.

3) **Generation of employment:** Based on the studies conducted by Ernst and Young in 2012, wind power creates 21,000 jobs a year for every billion invested in offshore wind in the EU [90]. According to the German Wind Energy Agency, almost 14,000 people were employed in the offshore wind energy sector in Germany in 2012. The localisation of the supply chain in these countries helps in the creation of more jobs.

4) **Impact on fisheries:** Trawling the seabed is one of the most destructive forms of fishing, using nets weighing as much as several tonnes each, that are dragged across the seabed. This could cause damage to the seafloor, could damage anchorage of moorings (in case of floating turbines) and subsea cables within the wind farm. Some offshore wind farms have banned trawling, however this restriction leads to an area of conflicting interests as fishermen will lose trawling ground. There is evidence that wind farms can benefit surrounding fisheries in the long term as restricted fishing provides a safe haven for juveniles which then 'spillover' into the surrounding areas.

Fishing is a major provider of livelihood for coastal communities in Gujarat and is considered to be one of India's most important fisheries. With over 17,000 mechanised vessels and a host of fishing depended shore-based industries, the State contributes approximately 21% (2004 figure) of India's total marine fish landings [91]. Major fishing harbours include: Veraval, Porbander, Mangrol and Jafarabad. Further study is needed to assess the social and ecological effect on these fisheries from offshore wind development.

[6] Calculated based on net plant load factor of 35%

10.6 National experience from relevant sectors

Some offshore wind power activities have similarities to practices from onshore wind, offshore oil and gas and ports and harbours industries. Applicability of EIA, Coastal Regulation Zone (CRZ) notifications, environmental protection laws as well as rules from the mentioned sectors are discussed in the following section.

EIA for onshore wind projects

- There are no particular guidelines for EIA of onshore wind power projects in India. In fact, under the Ministry of Environment and Forests (MoEF) regulation (2006 EIA notification), it is not mandatory (at the time of writing);
- Since offshore wind power will also have onshore activities, which may seek land clearances, there may be relevant regulatory applications under 'Land Acquisition and Land Diversions', 'Tribal Rights' and 'Forest Acts and Rules' for this sector;
- Socio-economic considerations are to be kept in the planning process for offshore wind projects. Local resident's land and their livelihood (e.g. fishing) fall under the requisite of a social impact assessment (SIA) or socio-economic impact assessment (SEIA). This may be carried out in a detailed EIA where the component of 'Land' can be addressed;
- Since, the 2006 EIA notification [92] is not applicable in the case of onshore wind farms, Environmental Clearance (EC) is not mandatory. However, if any wind farm (onshore) is located at the coastal boundary, then the 2011 Coastal Regulation Zone (CRZ) notification [93] is applicable which stipulates the activities permitted within the coastal zone. It is not implausible that further amendments may include coastal waters, hence affecting offshore wind power development.

EIA in Relation to the offshore oil and gas sector

- The schedule in the EIA notification, 2006 lists projects or activities requiring prior environmental clearance. Both offshore and onshore oil and gas exploration, development and production projects fall in category 'A' which specifies that the project proponent shall seek clearance from the central authority i.e. the MoEF. In the same conditions, it notes that exploration surveys (not involving drilling) are exempt provided the concession areas have got previous clearance for physical surveying.
- In the case of offshore oil and gas, it would largely depend on the survey methods adopted and the development/production scale and siting. Although the notification does not specify offshore wind projects in either of the categories ('A' or 'B'); EIA is a necessary tool for environmental management, and should be adopted when the Indian offshore wind industry takes hold;
- Land diversions and acquisition for onshore activities remain similar for this sector also. The Land Acquisition Act and the applicability of the Rehabilitation & Resettlement (R&R) Act [94] remain similar to any other sector where land is considered. Where the coastal region falls under a municipal corporation or municipality of Gujarat, the Gujarat Town Planning and Urban Development Act, 1976 [95] is applicable. This indicates the importance for offshore wind projects to consider detailed environmental as well as socio-economic surveys and studies;
- Offshore wind development siting assessments may fall within requisites of the New Exploration Licensing Policy (NELP). Under this, for offshore oil and gas exploration and production, the proponent is awarded the block by competitive bidding for exploration and production;
- In this sector, the CRZ notification 2011 and the EIA notification 2006 are applicable along with the MoEF's Environmental Protection Act (EPA), 1986 [96];

- Development of EIA and SIA guidelines for offshore wind projects are crucial to emphasise environmental management practices in an appropriate manner and direction. Although synergise exist with oil and gas there are also key differences that must be considered, such as a greatly reduced pollution risk from offshore wind, but a higher collision risk for ornithology.

EIA in Relation to Ports and Harbours

- EIA is generally mandatory for port and harbour projects but depends on whether it is an expansion project or Greenfield development [97];
- The majority of port and harbour activities are performed at the intersection of land and sea. Due to this locality, the sector comes under the purview of the 2011 CRZ notification. Applicability of the CRZ varies depending on location and scale of the activity;
- The 2006 EIA notification is also applicable, although specifications for the sector vary. The Land Acquisition Act and R&R Act are also applicable as is the Town Planning Act of Gujarat when it falls under a municipal corporation or municipality.

In summary, by understanding the relevant sectors and applicability of their environmental constraints, it is palpable that similar constraints may be applicable to offshore wind projects. Considering all the CRZs across the coast of Gujarat, CRZ- I, II or III will be applicable. Under the 2006 EIA notification and the EPA there are certain laws and rules which are applicable which are discussed within the next section.

10.7 Legislative framework in India applicable to offshore wind EIA

Apart from the EIA and the CRZ notifications, there are other regulations applicable for any development activity both at sea and on land (see Table 51). There are also certain international regulations from which lessons can be taken when formulating India's legislative framework on ESIA for future offshore wind development.

Table 51: Applicable Acts, Notifications and their Relevance to Offshore Wind Projects in India.
Source: [98], [99], [94], [100]

Environmental Laws, and Rules		
No.	**Acts, Notification Titles**	**Applications**
1.	The Environment (Protection) Act, 1986	For all activities which have pollution standards as per EPA rules.
2.	The Forest (Conservation) Rules, 2003	Where an offshore wind project's onshore activities fall within a forest area.
3.	The EIA notification S.O. 1533, Dated 14th September, 2006	For categorising the proposals of projects into Category 'A' or 'B' and indicating the mandate for Environmental Clearance (EC), Consent to Establish (CtE) and Consent to Operate (CtO).
4.	The Water (Prevention & Control of Pollution) Act, 1974 (The Water Act)	For any release or discharge of used or waste water or effluent from a manufacturing or operations sites on the coast or at the intersection of land and sea.
5.	The Air (Prevention and Control of Pollution) Act, 1981	For any kind of activity which generates or contributes to air pollution in terms of gases, fumes or particulate matter.
6.	Noise pollution (falls under EPA, 1086)	Presently there are no standards for the noise in the sea or sea surface. However, for the onshore activities it shall be applicable.

7.	The Wildlife (Protection) Act, 1972.	For the protection of marine and terrestrial wildlife from any development activities. It shall be applicable in the case of any cross- border movements of any living species which are categorised as endemic to India.
8.	The CRZ notification, 2011	Applicable with respect to the location of the site on land and the intersection of land and sea.
9.	The Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008	For the prevention of movement of any goods or commodities across the sea which have the potential to cause damage to the environment and living organisms. Their movement can be executed with prior clearances as stated in this act.
Socio-Economic Regulations		
10.	The Right to fair compensation and transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013.	For the rights of the people who own the land at a development site. It involves regulations concerning relocation of any family or community or village. This applies to offshore wind as onshore activities may involve land dealings.
11.	The Scheduled tribes and other traditional forest dwellers (Recognition of forest rights) Act, 2006 and Forest rules, 2007	If any tribal area falls near to the site.
12.	The labour laws- 1. The Factories act, 1948 (Act. No. 63 of 1948, as amended by the Factories (Amendment) Act, 1987 (Act 20 of 1987). 2. The Payment of wages act, 1936	For all employees/ labourers working onshore or offshore.

10.8 International treaties to be considered

Some international treaties that are to be considered for development of offshore wind power projects, in the case of shipping, are discussed briefly below. A recurring discussion on these is the control and verification of adherence to the regulations.

- International Maritime Dangerous Goods Code (IMDG-Code) - for the safe transport of dangerous cargoes and related activities;
- International Convention for the Prevention of Pollution from ships (MARPOL) - to prevent the pollution of the marine environment from operational discharges of oil and other harmful substances and the minimisation of accidental discharges of such substances;
- United Nations Convention on the Law of the Sea (UNCLOS), 1982 - with the obligation to prevent pollution damage by addressing particular sources of pollution, including those from land based activities, seabed activities, dumping, vessels and from or through the atmosphere;
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (UN Treaty), 1992 - implemented to reduce the movements of hazardous waste between nations and specifically to prevent transfer of hazardous waste from developed to less developed countries.

10.9 Suggested EIA framework

Since offshore wind power projects are new developments for India, a licensing and permitting framework will have to be developed that considers approaches from other sectors and international experiences. The basic regulatory themes that can be used to characterise a country's approach are:

1. The process of allocating sites or zones for development;
2. The level of support and assistance offered to developers through cooperation between the different government agencies and other private parties; to ensure appropriate guidance on compliance is given and ultimately to obtain required permissions;
3. Creation of a mechanism to centralise the administration of the regulatory system for this sector.

Under these three headings, the present understanding is to take guidance from the New Exploration Licensing Policy (NELP) bidding process from the offshore oil and gas sector to create a base for a similar process in offshore wind energy projects. Two potentially suitable ways of awarding a site to a developer are considered below:

a) The site may be developed under the notion of declaring suitable or feasible zones and allocating the sites based on the feasibility analysis;
b) The potential of the zone can be explored by the proponent after which the full clearance process for development is to be undertaken.

10.9.1 Revisions Required in India's Regulatory Framework for Offshore Wind Projects

The major point of concern in this whole process of licensing or leasing out the zones is whether there should be one stage of permitting a site, which may include exploration and development together, or whether there should be a two stage process, which includes two separate permissions; namely, one for exploration (e.g., seabed geology assessments for suitability of foundation types) and one for development. Either way, applicability of environmental management systems is to be considered. Considering that there are no guidelines for conducting ESIA for offshore wind power projects, the following points should be analysed.

1. The applicability of the EIA notification for considerations on how the environmental clearance process should be carried out.
2. What would be the extent of EIA notification applicable i.e. whether the proponent has to apply for exploration and development together or whether it has to be a separate application to the authority for the two stages?
3. What is a more feasible option considering India's regulatory system that ensures development of the industry along with environmental safety: a one or two stage process?
4. The National Offshore Wind energy Agency (NOWA) stands as the sole authority handling the permission process for offshore wind development. Application for the environmental clearance (EC) shall go to NOWA who will forward it to the relevant authority - MoEF in this case, or it could be a direct application to the MoEF. This process will have to be fixed for clarity on the regulatory pathways and be appropriate to support the development.
5. A revision in the EIA notification is required to develop specific criterion for offshore wind projects. Suitable specifications in the EPA are needed for standards on pollution parameters of all development activities.
6. The leasing or licensing period and exploration or development extent has to be specified based on the scale of investment and spread of the project.

7. Considerations from other relevant sectors are to be taken into account during the framing of guidelines for the offshore wind sector.

10.9.2 Seeking clearance from the State or the Central Government

As in other sectors, the rules and regulations need to be formulated if offshore wind projects are to seek clearance under EIA Categories 'A' or 'B' (in relation to EIA Notification, 2006).

1. This point is important to have statement of authority; as if it falls under Category A, it would be responsibility of the MoEF whereas if it fell under Category B, it would be responsibility of the SEIAA (State Environmental Impact Assessment Authority).
2. It is to be noted that since land activities may need to be located on the shores or coastal areas of Gujarat, it would be the State Government's authority. This is because 'Land' is a 'State issue'. As such for the project, the clearance is a Central or a State issue based on the project scale.
3. However, with offshore wind activities being mainly at sea, it would be largely under the Central Government's authority.

An addition in the offshore guideline and revision in the EIA notification, 2006 is required for offshore wind projects.

11 WIND MEASUREMENT STRATEGY SELECTION

11.1 Introduction

Development of a robust wind resource assessment campaign that minimises uncertainty in the project energy estimates, whilst managing the cost and schedule of the measurement effort is a complicated balancing act. Onshore, the options for measurement are relatively well-known, moderate in cost, and accepted by the financial community. Onshore wind projects typically use either multiple on-site meteorological masts as the primary method for wind resource characterisation or standalone LiDAR wind measurements (possibly with off-site masts and/ or modelled data). An offshore wind project with an installed met mast typically costs multiple times that of an onshore mast; hence the installation of multiple masts is generally cost-prohibitive. In addition modelled data are more difficult to validate without other high quality measured data for calibration and fixed remote sensing devices (such as LiDAR) can be more difficult to deploy without a suitable offshore fixed platform with minimum flow distortion around the structure. Floating LiDAR devices are not considered an industrial standard for standalone offshore wind measurements, yet. However, current floating LiDAR projects have shown good results and are expected to become widely accepted within the industry soon.

The objective of this section is to help potential developers and other interested parties plan an offshore wind resource measurement campaign that provides the best balance of the following four goals:

1. **Low cost** – Keeping expenses as low as possible during the development phase of an offshore wind project is critical for developers, particularly for projects that are not guaranteed to move forward and be constructed.

2. **Short schedule** – While offshore wind projects typically have long development schedules relative to onshore projects (often approaching ten years), it may not be feasible to conduct measurement campaigns throughout the entire development process. For example, some developers may not want to commit significant expenses to data collection while an offshore project is in an early permitting stage. Consequently, it is often necessary to condense the majority of data collection activities into one or two years.

3. **Low uncertainty** – Project financing is frequently driven by the uncertainty in project energy estimates, and a wide spread between the P90 (or P99) energy level and the P50 can make financing terms unacceptable. Minimising uncertainty to the extent possible is therefore critical for a successful project.

4. **High "bankability"** – Advances in resource assessment technologies need to be accepted by investors as well as project developers – if the investors do not have sufficient comfort with the data, a project will not be successfully financed. Many investors are hesitant to accept some innovative technologies, particularly if they have had bad experiences with those technologies on other projects (such as at onshore wind projects), and developers often do not wish to spend money to collect data with newer technologies if they do not have some assurance that the data will eventually be used.

In most cases, balancing these four goals will involve a combination of technologies at a project, and there will often be trade-offs among these four goals that make certain technologies and options more or less attractive at a site. If the schedule for a project allows for five years of data collection, there will be more opportunities to try higher risk but lower cost collection systems than for the same project if there is only one year available for data collection, as there will be more flexibility to change plans if the initial choices are not providing the necessary data.

11.2 Defining measurement objectives

The first step in developing a wind measurement plan is to establish clearly-defined objectives for the measurements. This is true for both onshore and offshore wind projects, but due to the cost of most offshore measurements it is especially important to ensure that the measurements are productive and contribute toward meaningful goals.

To help frame the objective of this assessment, it is worth discussing some issues that are intentionally not addressed, or are only presented in non-quantitative terms:

- **Project developers must assess how much uncertainty is acceptable.** This section does not specify target levels of uncertainty in wind resource assessments, but rather methods for analysing, quantifying, and reducing these uncertainties. How much uncertainty is "acceptable" must be determined by each developer based on their risk appetite and the requirements of their project finances.
- **Developers should consider uncertainties other than those related to the wind resource.** This section directly addresses only topics related to wind resource assessment and reduction in risk associated with wind resource characterisation. There are other uncertainties that contribute to the total uncertainty in a project energy assessment, such as uncertainty on turbine availability and other technical losses. These topics are discussed briefly in this section as they contribute to the overall uncertainty, but there is no discussion related to data collection to minimise these uncertainties.
- **Measurements other than wind measurements are needed as part of offshore site characterisation.** For the most part, this section focuses on assessment of the wind resource at a project, from the standpoint of reducing uncertainty in a project energy assessment. Other data are needed for complete site assessment and for project certification, including data on the wave climate, soil conditions and geotechnical data, and other parameters.
- **Almost every aspect is project-specific.** While this section presents a framework for developing a wind monitoring programme, the resources available for each project will be different, and the costs of measurement systems will vary from one project to another. For example, if a developer has access to an existing fixed platform within or immediately adjacent to the project area, the cost of mounting a fixed remote sensing device on the platform may be quite low, and this may be a good way to reduce uncertainties at minimal cost. An otherwise-identical project without such an existing platform would need to either construct a fixed platform to collect the same data at much greater expense or deploy floating remote sensing devices which may have increased uncertainties and operational risks

Offshore measurement campaigns may have many potential objectives, depending on the needs of each particular project. Objectives should be as specific as possible in terms of target budget, timeline, acceptable uncertainty, and any other factors relevant to the developer. Example objectives may include the following:

- Collect data to reduce the overall uncertainty on project wind speed such that the long-term P95 is within a specific percentage of the P50 at the time of the project energy estimate (expected at a specific time);
- Collect sufficient data at the turbine hub height to characterise 50-year extreme gusts and other parameters as needed for turbine suitability assessments and project certification;
- Collect whatever data is expected to minimise uncertainty in the project energy estimate while staying under a specific budget limit; and

- Measure winds using equipment that will then be used for power performance testing once the project is constructed.

This section largely focuses on data for characterising long-term mean conditions at project sites, particularly from the standpoint of minimising uncertainty in these conditions in project energy assessments. However, other objectives may have slightly different needs and data collection requirements. For example, characterisation of extreme conditions generally requires gust data that may not be available from some data sources that only report (for example) hourly average winds. Discussion of these issues is provided where appropriate, but as every project is different the specific needs and restrictions of each should be considered while establishing objectives.

In most cases, measurements will need to be conducted for at least one full year at all projects to accurately characterise annual conditions and for meaningful extrapolation of extreme conditions. In some cases there may be a desire or requirement to deploy measurement system for less than a full year; for example, if aerial measurements are conducted. In these cases it may be possible to conduct measurements at a site multiple times in a year to make sure that annual conditions have been measured (this is referred to as seasonal sampling). If seasonal sampling is not employed and if data are collected only for part of a year there may still be uncertainty about how well these results represent the behaviour over a full year. This may be acceptable if the data, in spite of the uncertainty, provide valuable new information. An examination of numerous data sets indicates that seasonal variations may be significant at many sites. Thus, to adequately characterise the conditions over a year, either seasonal sampling or longer measurement durations are usually needed.

11.3 Siting recommendations

It is important to consider the local environment where the measurements are collected. Certain aspects of the measurement site can impact the accuracy of the measurements or reduce the data recovery.

Siting considerations are listed below:

- **Large structures** such as oil platforms can hinder the understanding of the free-stream wind speeds, particularly for measurements near or lower than the height of the structure. To the extent possible, measuring near these obstructions should be avoided;
- **Wave movement** can affect buoy or floating platform measurements in a number of ways:
    - Not measuring at a consistent height due to the up and down motion of the buoy and/or the tilting of the instrument;
    - Measurement of non-horizontal wind speed. Cup, prop vane, and ultrasonic anemometers will report inaccurate wind speeds when they are tilted from the horizontal axis;
    - The movement of the waves will require that all equipment is sufficiently secured to the buoy or floating platform;
    - Wave shadowing can affect wind speed and direction measurements of instruments near the water surface. Wind speed and direction instruments should be located sufficiently above the water surface to avoid wave shadowing under typical sea conditions at the site, and at hub-height whenever feasible;
- **Water and corrosion resistant** equipment should be used;
- **Weather conditions** at the site should be compared to the operating specifications of the equipment and the equipment should be ruggedised if necessary;

- **Technology-specific siting requirements** exist and should be accounted for. For example, sodars (sonic detecting and ranging) should be sited in locations to avoid noise interference. Sodar measurements can be affected by echoes from nearby structures. Mounting or anchoring schemes that cause wind-generated noise or resonate with the acoustic signal should also be avoided for sodars;
- **Access for maintenance** should be considered. To the extent possible, the measurement site should be in an accessible location and be designed so that instruments can be maintained on a regular basis;
- **Other considerations** such as marine wildlife and birds may need to be accounted for. For example, provisions for preventing seals from accessing floating buoys may be necessary to avoid possible damage;

11.4 Hub-height meteorological mast

The conventional hub-height meteorological mast, fitted with cup anemometry, is the most prevalent technology type. Despite a range of alternative measurement technologies emerging in recent years, measurements from cup anemometers mounted on mast structures are the long-established standard in the wind energy industry, and the development of wind turbine power characteristics are based to some extent inherently on cup anemometer technology. An effective design and operation of a site mast is paramount to reducing uncertainties associated with the predicted wind climate. However for an offshore project a hub-height meteorological mast is capital intensive compared to alternative technologies in wind resource assessment. Therefore, more cost effective technologies should be explored for early validation of wind resource.

11.5 Fixed platform remote sensing

The use of remote sensing devices is promising for offshore measurements; however, there are two main constraints: reliability of the devices and the cost of the platform. There are a number of LiDAR devices that have been developed and commercialised for the wind resource measurements. This section focuses on those devices installed on fixed platforms and free from any vessel or wave movement. The remote sensing device may be placed on an existing offshore structure or on a platform built specifically for wind resource measurements.

Remote sensing, in this case, refers to instruments that sit on a support platform and measure horizontal and vertical wind speeds above the instrument using laser light (LiDAR; Light Detection and Ranging). These instruments are typically designed for use in wind resource assessments and measure wind speeds every 10 or 20 m above the ground from 40 m (or possibly lower) to 150 m (and possibly higher).

LiDAR, emit light at a specific frequency which is reflected from aerosols suspended in the air. LiDARs may emit a short pulse of light (a pulsed LiDAR) or a continuous beam (a continuous wave LiDAR). Wind speed is determined by the frequency of the reflected light. That frequency depends on the speed of the aerosols (which is assumed the same as the wind speed). A LiDAR can only measure wind speeds along the direction of the laser beam ("radial wind speeds"). Each type of LiDAR operates in a slightly different fashion.

- In a pulsed LiDAR system, the distance along the beam at which a wind speed is calculated is determined by the travel time of the light. Thus, a pulsed LiDAR can determine radial wind speeds at a variety of distances along the beam during each measurement. That one measurement, though, only provides information from one direction. To determine wind speed and direction and vertical wind speed, measurements from three or more different directions are needed. Thus, pulsed LiDAR systems might determine three different radial velocities each from one of three different directions, with radial velocity measurement separated by about a second. For example, the three different directions might be inclined about 30 degrees to vertical and directed at points 120 degrees around the compass. The results of the three radial velocity measurements are then combined to determine either wind speed, direction and vertical wind speed or the perpendicular components of the wind (longitudinal, lateral and vertical). In these systems, the time it takes to get a new independent measurement at any given height, the "measurement period," is the time it takes to get three new radial velocity measurements or about three seconds;

- A continuous wave system will typically focus at one distance, collect measurements and then focus at another distance. The LiDAR beam is inclined about 30 degrees to vertical and rotated to measure at multiple points around a circle. About every second, the lens refocuses the beam at another height and measurements are made at that height. The measurement period (again, the time to get a new independent measurement) of such an instrument is about one second;

In summary, in both cases, wind speed measurements are acquired at a variety of heights and from a variety of beam directions. Wind speeds are then determined from these measurements. A pulsed LiDAR measures at multiple heights in one direction and then emits a beam in another direction and then a final direction to determine the wind components. A continuous wave LiDAR measures in multiple directions and at one height and then refocuses at another height and then another height.

In both cases, a fast digital processor collects all of the information needed and calculates the final wind components which are stored in memory or transmitted over a wireless or satellite system to users.

Wind speeds can typically be determined up to about 200 m but measurements depend on the amount of aerosols in the air. In clear air wind speeds may only be measureable at lower heights (perhaps only up to 100 m or lower).

Figure 31: WindCubeTM LiDAR on an Offshore Platform. Photo Courtesy of Leosphere

11.6 Potential siting locations at identified development zones

At the time of writing this report, the Indian government is finalising its national offshore wind policy. The option of using LiDAR devices on existing offshore oil and gas platforms or lighthouses may be an attractive cost effective option for early validation of wind resources at the identified development zones.

There are 11 identified oil and gas platforms in the Gulf of Khambhat region listed in Table 52. There currently are no other known ongoing exploration or production activity.

Along the coastline of Gujarat, from Dwarka to Dadar and Nagar Haveli, there are 32 onshore lighthouses identified in Table 52. This stretch consists of all the identified eight zones for offshore wind project development in Gujarat.

The preferred option is to place the LiDAR device as close as possible to the development zones free from any obstructions. The following section focuses on high level desk-based siting options of installing a LiDAR device at the eight potential development zones.

Table 52: Potential structures for LiDAR deployment.

Offshore Structure	Location/ Name	Latitude (N)	Longitude (E)	Approx. Distance from Centre of Zone (km):							
				A	B	C	D	E	F	G	H
Platforms	Platform 1 CB 12	20° 5'33.69"	71°48'17.90	63	107	106	98	31	146	364	303
	Platform 2 -	20°20'19.60	72° 1'26.38"	73	74	116	61	14	110	370	312
	Platform 3 -	20°19'53.42	72° 7'33.97"	84	74	128	53	15	107	380	323
	Platform 4 -	20°32'41.31	71°58'41.53	67	50	107	57	39	90	355	298
	Platform 5 -	20°35'57.39	72° 2'10.45	75	43	114	50	45	82	358	303
	Platform 6 C 23	20°32'3.50"	72° 9'9.64"	86	51	127	38	39	83	373	317
	Platform 7 -	20°41'0.63"	72°13'32.77	98	36	135	30	58	64	373	320
	Platform 8 C3GPA	20°43'0.00"	72°19'9.00"	109	38	146	22	66	57	382	329
	Platform 9 NTP 2	21° 3'0.00"	72°23'0.00"	132	34	161	52	105	17	377	329
	Platform 10 -NTP 1	21° 3'41.42"	72°25'18.23	137	39	166	53	108	16	381	333
	Platform 11	21° 3'23.79"	72°37'0.71"	155	60	186	54	117	29	402	355
Light houses	Alang	21°24'2"	72°11'1"	144	54	161	98	141	35	347	304
	Bhavnagar Old Port	21°48'3"	72°09'2"	182	100	190	145	188	77	340	305
	Bhirbhanjan	20°53'9"	70°23'0"	123	190	78	236	202	228	181	120
	Cavaleiro	20°42'8"	70°59'8"	54	127	12	167	132	168	248	189
	Daman Ganga	20°24'6"	72°49'9"	160	104	202	45	88	105	447	393
	Diu Head	20°41'5"	70°49'7"	69	145	24	186	148	187	234	173

Offshore Structure	Location/ Name	Latitude (N)	Longitude (E)	Approx. Distance from Centre of Zone (km):							
				A	B	C	D	E	F	G	H
	Dwarka Point	22°14'2"	68°57'5"	344	381	301	438	420	404	53	116
	Ghogha	21°41'5"	72°16'6"	177	89	190	128	175	60	354	316
	Gopnath Point	21°12'2"	72°06'6"	120	29	140	81	116	34	343	296
	Hazira	21°05'5"	72°38'6"	159	62	189	57	121	29	404	356
	Jafrabad	20°51'4"	71°22'9"	48	81	49	127	107	122	278	223
	Jegri Island	21°02'4"	71°48'2"	84	34	101	91	100	70	315	265
	Jhanjhmer	21°10'8"	72°03'7"	114	25	134	81	112	39	338	291
	Johnston Point	21°48'6"	72°12'8"	185	101	194	144	188	76	346	310
	Kachhigadh	22°19'8"	68°56'9"	352	387	309	444	427	409	63	125
	Kanai Creek	20°48'7"	72°49'7"	165	83	202	43	109	66	432	381
	Luhara Point	21°39'5"	72°32'9"	192	96	210	122	178	56	384	345
	Mangrol	21°06'5"	70°06'3"	162	222	118	271	241	257	140	80
	Navadra	21°56'5"	69°13'9"	299	340	255	396	375	365	20	71
	Navibandar	21°27'0"	69°47'2"	214	264	170	316	292	293	88	38
	Nawabandar	20°44'4"	71°04'8"	49	117	17	158	125	158	254	196
	Perigee Light Vessel	21°41'50"	72°18'4"	180	91	193	129	177	61	357	320
	Piram Island	21°35'9"	72°21'2"	173	80	189	115	165	47	363	324
	Porbandar	21°37'22"	69°37'10"	241	286	197	340	318	314	63	34
	Ruvapari	21°46'7"	72°14'0"	183	98	194	139	185	71	349	313
	Saiyad Rajpara Bandar	20°47'5"	71°12'3"	45	101	30	144	116	142	264	207
	Shialbet	20°54'2"	71°31'6"	56	64	66	113	100	105	291	237
	Simar	20°46'5"	71°09'0"	46	107	25	150	120	148	260	203
	Umargam	20°11'7"	72°45'0"	155	117	199	59	78	126	450	394
	Valsad Khadi	20°37'8"	72°53'2"	168	97	208	44	104	87	445	393

Offshore Structure	Location/ Name	Latitude (N)	Longitude (E)	Approx. Distance from Centre of Zone (km):							
				A	B	C	D	E	F	G	H
	Veraval	20°54'6"	70°21'2"	127	194	82	240	206	231	177	115
	Wasi Borsi	20°56'1"	72°45'7"	163	73	197	47	115	50	420	371
Ports/ Islands	Bhesla Rock	20°76'7 ''	71°17'6''	98	97	85	154	151	125	252	205
	Hazira	21°5'6"	72°37'48"	158	62	189	57	121	28	403	356
	Porbandar	21°37′60″	69°35′60″	243	289	200	343	320	316	60	34

12 KEY FINDINGS AND RECOMMENDATIONS

A high level assessment of offshore wind potential for Gujarat has been completed. Using existing public domain data, development constraints were modelled to identify the eight most viable zones for offshore wind energy. Following zone selection further technical, financial and social-environmental studies were conducted focusing on the key components that make up an offshore wind project. Where possible these studies have been conducted at a zone level but will be investigated and analysed further during ongoing FOWIND work packages.

Compared with the established onshore wind industry, offshore wind is a relatively new technology. This immaturity combined with additional technical challenges for offshore wind typically means it is more expensive to produce a unit of energy offshore than it is onshore. But the typically stronger, more consistent wind at sea means that there often exist real opportunities to narrow the gap in the creation of a viable offshore wind sector. Currently it must be noted that the estimated offshore mean wind speeds are only marginally greater than those known to be found onshore in Gujarat. However given the high level of uncertainty associated with the available data and in particular the offshore wind resource there may exist significant room for improvement in future studies and ongoing FOWIND work.

This lack of definitive on-site wind measurements offshore has only allowed for some broad conclusions to be drawn but a LiDAR wind measurement campaign is due to commence soon under the FOWIND project with the aim to reduce this wind resource uncertainty. Until this offshore validation data is obtained the FOWIND consortium recommends that the results presented in this study are used solely for pre-feasibility purposes only.

The remainder of this chapter presents; short section summaries, the key conclusions drawn from this pre-feasibility study and recommendations for ongoing work.

12.1 Offshore wind regime

To date no publically available on-site wind measurements have been recorded within the Gujarat offshore zone. Hence this study had to rely on available satellite data and mesoscale modelling methods. Without offshore measurements to provide validation points there exists a high level of inherent uncertainty and the presented results must be treated with due caution. An offshore measurement campaign is essential for the ongoing feasibility and development of offshore wind in Gujarat.

Wind speed spatial variation has been presented for projected turbine hub heights of 80 m, 100 m and 120 m above sea level. For a height of 120 m above sea level modelled mean wind speeds were in the range of 6.8 to 7.0 m/s (see Table 4 for further details). Recent European projects are known to possess mean wind speeds in the range of 8 to 10 m/s hence the values predicted in Gujarat from the mesoscale model are significantly lower. However given the high level of uncertainty and lack of offshore validation these results should be considered only for pre-feasibility and further certainty is required to pin point the best specific development sites within Gujarat.

12.2 Selection of potential wind farm zones

The eight potential zones, considered most suitable for offshore wind energy development, were identified by pragmatically ranking their compliance with a set of defined technical and environmental parameters. The key hard constraints, considered immovable for offshore wind farm development were as follows; offshore wind resource, the Indian Exclusive Economic Zone (EEZ), feasible water depths, proximity with construction ports and distance to transmission grids. Further constraints were also considered within the analysis, such as; the proximity to pipelines, proximity to oil & gas platforms, proximity to shipping lanes, visual impact, seismic risk and cyclone risk. Where constraints are considered significant at a zone level, such as presence of oil and gas platforms in Zone B, either exclusion zones have been established or statements made within the results table. Environmental factors such as coral reefs and mangroves are likely to impede development in some zones within Gujarat but this will be investigated further as part of future FOWIND studies. Additionally some areas of Gujarat exhibit high tidal currents, which in extreme cases could preclude development or at best make installation a challenge (for example the Gulf of Khambhat). Existing and further constraints will be investigated in more detail during the later full-feasibility study.

Eight zones have been identified with mean wind speeds in the range of 6.8 to 7.0 m/s (at 120 m AGL) and water depths in the range of -15 to -43 mLAT. At this stage no zones have been excluded and will be investigated further during full-feasibility. However zones located within the tidal current extremes and shipping lanes of the Gulf of Khambhat, such as Zone F, have been noted as risks.

12.3 Turbine suitability

The FOWIND consortium has completed a review of potential wind turbine offerings for the Gujarat Region, given a commercial turbine procurement target of 2020. A pre-feasibility level turbine screening study was conducted based on the following key selection drivers:

- Site suitability (ability to withstand the site climatic conditions over the 20 years design operating life);
- WTG track record (a loose measure of wind turbine reliability);
- Suitability of wind turbine to the site foundation selection; and
- Site specific power production (which contributes significantly towards the cost of energy).

Consideration was given to the known site-specific climatic conditions within Gujarat and the likely turbine class requirements to meet these conditions (e.g. IEC 61400-1 edition 3 turbine classification). Turbines are classed by three main parameters: the average wind speed, extreme 50-year gust, and turbulence. Mean wind speeds identified from the mesoscale modelling indicate a requirement for IEC Class III and above (noting the uncertainty without onsite wind measurements). Regarding extreme wind speeds further investigation is required, especially given the typhoon risks within this region. In lieu of long term measurements, it has been possible to estimate (with noted uncertainties) a 50-year return gust wind speed using the Indian Standard relating to Codes of Practice for Design Loads for Buildings and Structures. By applying the standard approach site gust wind speeds of 67.6 m/s for zones A to F and 74.4 m/s for zones G & H were estimated. Examination of IEC 61400-1 edition 3 indicates that these conditions are very close to (zones A to F), or exceed (zones G & H), IEC Class I limitations (Class I 50 year return gust wind speed limit is 70 m/s). Turbine IEC turbulence classifications A or B have not been identified at this stage but will largely depend on layout and resulting wake interaction effects. Based on the assessment, Class I or S wind turbines were taken forward for further assessment.

Offshore wind turbines with a significant operating track record are few and far between in a market dominated by a few suppliers. The Siemens G4 platform will have accrued a substantially stronger track record than the other WTG's considered, with the Vestas V112-3MW platform (including onshore experience) coming in second place. However a strong track record may come at a price premium and it should be noted that there may be opportunities to partner with organisations which are bringing new WTG's to the market. This may result in more favourable economic conditions with respect to turbine procurement in return for sharing the risk associated with the lack of a proven offshore track record.

There still exists significant uncertainty with regards turbine type selection; significantly with the site-specific climatic conditions that will require on-site wind measurement data and extreme wind speed

(Typhoon) studies to be undertaken. Selection should also carefully consider the suitability of the proposed turbine and foundation combination.

12.4 Zone level energy production

The FOWIND consortium has conducted a high level energy production assessment for each of the identified zones in Gujarat. The assessment was undertaken assuming uniform layouts for both 150 MW and 504 MW wind farm capacity options, using the generic 4 MW and 6 MW wind turbines. It is important to take note of the preliminary nature of these estimates and the uncertainties highlighted within the report.

For the eight zones and with deployment of the Generic 4 MW turbine, Project Net Capacity Factors were estimated in the range of 18.5 % and 25.9 % (depending on the particular zone and MW capacity of the farm). When deploying the 6 MW Generic turbine Project Net Capacity Factors were estimated in the range of 21.9 % to 29.7 %. While these values would broadly be in line with capacity factors achieved for UK Round 1 projects [101], values are still considered low because turbine availabilities have been assumed in-line with the current industry standards throughout analysis (approximately 95%). Low capacity factors in early UK projects were largely a result of poor turbine reliability and availability resulting from un-optimised maintenance access strategies and worse than anticipated weather restrictions. Current and future European projects are set to achieve significantly higher capacity factors due to the development of optimised operation and maintenance strategies and improved turbine reliability. For example, recently Danish offshore wind farms have been reported as achieving a total average capacity factor of greater than 40 % [102]. The UK average capacity factors have grown significantly over the years and current averages are reported between 35 % and 40 % [103]. This again highlights the critical need to obtain on-site wind measurements within the Gujarat offshore zone.

12.5 High level foundation and geotech screening study

A pre-feasibility foundation type screening and preliminary seabed desk top study was conducted by the FOWIND consortium. The study has focused on common foundation types rather than more novel variants. The following key parameters have been discussed and should be considered as a minimum during future foundation selection studies:

- Foundation Cost;
- Water Depth;
- Wind Turbine MW Class and Frequency Window effects;
- Ground Conditions;
- Local Installation Vessel Availability;
- Local Fabrication Capability;
- Extreme Wind Speeds (Typhoons);
- Earthquake Loading; and
- Waves and Currents.

A number of Geotechnical and related seismic risks and hazards have been identified in the Gujarat region as part of the study but given the limited availability of data at this stage, further investigation will be required to identify hazards at a zone specific level.

The pre-feasibility screening was based on a number of key assumptions and the following qualitative factors:

- Wind turbine MW Class (4 and 6 MW) – high level loading and structural dynamic effects; and
- Zone Water Depth.

From the screening it was concluded that monopile, jacket and tripod foundations would be likely choices to take forward for the next stage of investigation and if the local fabrication supply chain permits, there is likely merit in the detailed consideration of XL Monopiles. This is not to say others could not become suitable following analysis of more detailed data during later project stages (for example higher resolution metocean and geotechnical data).

12.6 High level wind farm electrical concept description

In order to transmit power from the offshore wind farm to the onshore grid system a dedicated electrical infrastructure is required. This electrical infrastructure typically constitutes about 20% of the project CapEx and this section of the report introduced high-level requirements for offshore wind electrical systems and an introduction to possible grid connection points in Gujarat.

Based on recent industry experience, The FOWIND consortium considers that for an offshore wind farm with a capacity of 150 MW, connection via an offshore substation to a 220 kV node would likely be most suitable; whilst a higher capacity plant (504 MW) would require connection to a 400 kV system node.

The Gujarat region has been highlighted as having a number of operational transmission lines and substations near the coast which could facilitate offshore wind energy output. The existing transmission infrastructures may be sufficient to allow some development of offshore wind power in Gujarat but detailed studies are required to assess in full if some transmission upgrades would be necessary. Further grid connections studies are being conducted as part of the ongoing FOWIND work scope.

12.7 High level installation consideration

The FOWIND consortium provided a high-level overview for key installation considerations and methodologies for optimisation. The key areas of focus for installation studies are ports, vessels and strategy planning.

Besides the main wind farm infrastructure, the port is one of the most important components in offshore wind construction. The key parameters for selection include; distance to shore, maximum vessel dimensions, storage areas and inter-connections. Gujarat has a total of 43 identified ports however many of these are small and would require significant development and capital investment. The preliminary screening study has identified seven ports with some potential, namely: Dahej, Hazira, Jafrabad, Nargol, Pipavav, Porbandar and Magdalla. Ports will be investigated further during future FOWIND studies.

Construction of offshore wind power project requires specialised vessels. In regions where the industry is well developed vessels built specifically for offshore wind requirements are now common, however in newly developing regions such as India it is anticipated that utilisation and modification of vessels from adjacent sectors will be required until a sufficient supply chain develops. Up to 18 different types of vessels can be required during the offshore wind farm project life (typically 20 years) and some of the major types have been discussed. The key parameters for vessel selection can be summarised as follows; metocean conditions, soil conditions, component size and distance from shore. India has a total of over 700 offshore vessels with a total gross tonnage of over 800,000, however most of these are related to the oil and gas industry and are not optimised for offshore wind. This will likely leave India with three main vessel supply options:

- Modifications of the existing oil and gas, fishing or civil engineering vessels specific to the requirements for both construction and operation and maintenance phases of offshore wind projects. This option should be considered at least for offshore support vessels and work boats.
- Design of specialised vessels for offshore wind project installation. The development of specialised vessels is largely dependent on the scale of deployment of offshore wind in India.
- Using the services of the existing European or Asian offshore wind vessels may be a favourable short term solution. This option should be considered for wind turbine, foundation and substation installation vessels.

There exist various possible combinations for the assembly, transportation and installation (T&I) of wind farm components. Some of these are discussed within the report however the key recommendation would be to conduct site-specific transportation and installation planning during the early project development stages, before critical design decisions are made. The transport and installation strategy should be optimised for the specific conditions of each individual project site. Careful consideration of the metocean conditions, transit distances and vessel characteristics is necessary. The extreme conditions found within Gujarat, such as Typhoons, are likely to play a critical role in defining strategies. With a typical project share of up to 20% of the total CapEx, T&I expenses have a significant impact on the profitability of the wind farm. Therefore optimising the strategy and reducing potential downtime due to weather can support cost reduction and mitigation of schedule over runs during the T&I phase of the project. Vessel options and installation strategies will be investigated further during future FOWIND studies.

12.8 Operation and Maintenance considerations

As the name suggests Operations and Maintenance activities can be divided into two main tasks:

1. Monitoring, controlling and coordinating the wind farm operations; and
2. Maintenance activities of the turbines and the balance of plant (BoP), which are typically sub-categorised into; scheduled and unscheduled maintenance.

The access logistics associated with these maintenance activities, are one of the most significant operational challenges facing the offshore wind energy market. Access strategies can be categorised into three main types; onshore-based marine access, helicopter access and offshore-based marine access. Onshore-based marine access (e.g. workboats) is the most common approach to date, however is heavily restricted by the sea-state during transfer onto the structures. This section presented a preliminary investigation into suitable O&M strategies for Gujarat and estimates for OpEx (Operational Expenditure). Common access vessels are introduced and minimum typical requirements for O&M ports are discussed. The closest O&M ports considered suitable for each zone have been identified, namely; Pipavav, Navabandar, Hazira, Nargol, Dwarka and Porbandar. However, a detailed study and analysis needs to be carried out in order to draw final conclusions.

In order to select the most suitable O&M Strategy DNV GL has used its in-house model: "O2M Optimisation of Operations and Maintenance" to simulate a variety of O&M strategies at each of the selected zones. It has been noted that the use of helicopters or motherships is not envisaged to prove optimal for most scenarios. The inclusion of helicopter operations to support wind farms can be of significant relevance for a large number of turbines (for example for the 126 x 4 MW turbines) but will prove suboptimal for the rest of the configurations with a lower number of turbines (25, 38 and 84). However, due to the significant logistical and regulatory complexity added to a project and related to helicopter operations, it has been deemed appropriate to rule out these strategies and assume that all first offshore wind projects in India will be based on the most proven work boats access methodologies.

Considering only workboat access methods preliminary estimates for OpEx and availability have been presented for each identified zone, farm capacity (150 & 504 MW) and generic turbine MW classes (4 & 6 MW).

12.9 High level preliminary project costing

The development of offshore wind energy is affected by a wide range of interconnecting factors. Wind resource is the most significant factor affecting offshore wind Cost of Energy (COE). Sites with a good wind climate generally exhibit a lower COE. High-level preliminary COE modelling for the identified potential offshore wind development zones was conducted using both fixed and optimised base line assumptions. The Levelised Cost of Energy (LCOE) has been calculated using DNV GL's in-house Cost of Energy model. This considers the dynamic balance of capital expenditure (CapEx), operational expenditure (OpEx) and annual energy production (AEP). The results have indicated that:

- Zones A and B represent the most economic locations for offshore wind developments in Gujarat with 6 MW WTGs;
- Zones C and F in Gujarat, also present reasonable conditions for the development of offshore wind (Note: High tidal flows in at least Zone F have been identified that may limit installation or may result in increased installation cost); and
- Offshore wind developments comprising larger wind turbines are more economic than those comprising smaller turbines. This reflects current development in Europe and the general move to larger turbines.

It should also be noted that the cost of energy calculated in this analysis is significantly higher than that for current commercial developments in Europe. The primary driver behind this cost is the local wind resource: mean wind speeds used in the modelling are considerably lower than those exploited in Europe, with a consequent reduction in annual energy production over which the project costs can be distributed. Currently the COE model only considers European unit cost rates and hence there may be opportunity to reduce CapEx/OpEx costs further by considering local unit cost rates. This will be investigated further in later FOWIND studies, however local wind resource is still anticipated to be the driving parameter for LCOE. It is critical offshore measurements are obtained to validate the current wind resource maps.

12.10 Risk considerations identified

When planning offshore wind farm projects, all decisions must be considered regarding potential future actions, although outcomes cannot be foreseen with certainty due to incomplete information. This uncertainty associated with all business activity is defined as risk. This section provided a high level qualitative assessment of the principal risks for the potential offshore wind farm zones identified in Gujarat. It is important to ensure that significant risks are managed and that mitigation measures are identified. Risks were characterised into three major categories (High, Medium and Low) with "High" indicating the risk is considered "Not acceptable" and mitigation through an alternative solution is likely to be required. Further tasks have been identified as "Medium" indicating that mitigation measures would likely be required to reduce risks to "as low as reasonably practicable" (ALARP) levels. At this preliminary stage the following tasks have been highlighted as "High" risk and will be recommended as priorities for mitigation measures in future FOWIND work:

- **Wind Resource**: high uncertainty of the wind resource assessment;
- **Metocean climate** (water): high uncertainty and limited availability for wave and current data;

- **Geotechnical conditions**: there is only limited information on the seabed geology of the Gujarat region available; and
- **Grid connection**: grid availability.

12.11 Environmental and social impact

This section briefly discussed the potential impacts, regulatory mechanisms and protocols for environmental clearances. A high level predication of environmental and social impacts is provided for the identified zones in the State of Gujarat.

To date there is no regulation in place stipulating ESIAs for the wind sector in India. As the impacts of offshore wind power project developments are highly dependent on the site and scale of the project, pre-construction analysis is crucial. Internationally, a number of studies are conducted during the exploratory phase to ascertain the environmental and social impacts. Strategically targeted data collection and modelling is required to determine the long term effects; the cumulative effect of proliferating installations, and to help regulatory authorities make decisions on wind farm siting.

Just like any other industry, the offshore wind power sector will need specifications in the EIA notification and guidelines to carry out environmental monitoring studies. Appropriate standards and limits are required for different pollution standards relevant to this sector. Pre- and post-construction monitoring portfolios will need developing to assess the status of and impact on the environment.

Gujarat is home to sensitive marine ecosystems. For example, a considerable area within the southern coast of the Gulf of Kutch is declared as a marine national park and sanctuary, designated to protect the coral reefs. Mangroves are known to be present in the Gulf of Khambhat and in sparse density along the Saurashtra coast. Apart from corals and mangroves, other living organisms may also be impacted due to the development of offshore wind. The estuaries of South Gujarat which meet the Gulf of Khambhat are feeding grounds for whale sharks, and Dugongs are found along the Gujarat coastline. The coast of Saurashtra acts as a hatching ground for turtles and the region from the Jamnagar coast to Okha supports sparse corals and is of archaeological significance.

It has not been possible to assess all the environmental constraints at this time. At this stage, focus was given to spread and density of mangroves and corals along the Gujarat coastline. Long-term, a full ESIA is required to assess the type and scale of impacts that may occur.

12.12 Wind measurement device location

The importance of obtaining offshore wind measurements has been highlighted as a major project risk throughout this pre-feasibility study. In later stages of the FOWIND project a LiDAR wind measurement campaign is scheduled to help mitigate this risk. This section of the report presented high-level recommendations for the development of a robust wind resource assessment campaign and identified some potential siting locations within the identified development zones. These included oil and gas platforms, light houses, ports and islands. The list is non-exhaustive and at this stage will be subject to further investigation in later FOWIND studies.

12.13 Recommendations for ongoing work

The Consortium would recommend the following activities to support the feasibility and development of offshore wind in Gujarat. It is highlighted were these recommendations will form part of the ongoing FOWIND project work scope:

- **On-site wind measurement campaign** – in later stages of the FOWIND project an offshore LIDAR wind measurement campaign is scheduled to help mitigate this risk;
- **Full Feasibility Study** – Pilot Project Site Selection, Preliminary Engineering, cost modelling and socio-environmental investigations; to be included within the FOWIND full-feasibility study;
- **Extreme wind speed studies considering typhoon risk** – to be conducted to some extent in the FOWIND full-feasibility study;
- **Gathering further constraint data, metocean data and ground related data (Geophysical and Geotechnical) –** to be conducted to some extent in the FOWIND full-feasibility study;
- **Logistics and Infrastructure Study** – to include port selection, storage logistics, transportation requirements, vessel selection, supply chain analysis (throughout the project life-time; development, procurement, detailed design, fabrication, transportation, installation, commissioning, operation and decommissioning) – to be included within the FOWIND Infrastructure and Logistics study;
- **Grid Connection and Transmission Study** – to be included within the FOWIND Grid Connection Study;
- **Preliminary Environmental and Social Impact Study (ESIA)** – to be conducted to some extent in the FOWIND full-feasibility study;
- **Stakeholder Engagement Workshops** – to be conducted to some extent as part of FOWIND's stakeholder activities;
- **Development of a supportive National and Local Policy environment and guidelines to promote development in Gujarat –** scoping and review of India's existing policy framework for offshore wind will be undertaken in the context of India's electricity act 2003 which considers wind power and electricity.

13 REFERENCES

[1] FOWIND, “Project Inception Report,” 2014 a.

[2] GWEC, CSTEP, WISE, DNVGL, “Facilitation Offshore Wind in India Project Inception Report,” 2014.

[3] L. Xi, M. B. McElroy and J. Kiviluoma, “Global potential for wind-generated electricity,” Proceedings of the National Academy of Sciences of the United States of America, 2009.

[4] NREL, “Annual Wind Power Density at 50 m,” 2011. [Online]. Available: http://en.openei.org/wiki/File:QuikSCAT . [Accessed 12 06 2014].

[5] UNEP-NREL, “Offshore Wind Map (2005). GIS data developed by the National Renewable Energy Laboratory, which is operated by the Midwest Research Institute for the U.S. Maps,” 2005. [Online]. Available: http://en.openei.org/datasets/taxonomy/term/471?page=1.

[6] NREL, “Prepared a global offshore wind map that included India’s EEZ,” 2012. [Online]. Available: http://irena.masdar.ac.ae. [Accessed 23 04 2014].

[7] Sander-Partner, “Sander-Partner Global Wind Map (prepared using MERRA data for mean wind speeds at 59m hub height),” 2011. [Online]. Available: http://irena.masdar.ac.ae .

[8] DTU Risø & C-WET, “ Offshore Wind Potential in South India from Synthetic Aperture Radar,” 2011.

[9] INCOIS, Assessment of Wind Energy Potential Along the Indian Coast for Offshore Wind Farm Advisories., 2011.

[10] C-WET, “Indian Wind Atlas,” 2010.

[11] WinD Force Management, “Offshore Wind Power Development in India,” 2014.

[12] Oldbaum Services Ltd, “Offshore Wind Potential Tamil Nadu India,” 2011.

[13] “Anemoscope User’s Guide,” Canadian Hydraulics Centre and Environment Canada, 18 05 2013. [Online]. Available: http://www.anemoscope.ca/Documents/AnemoScope_User_Guide.pdf.

[14] “Global Map V.1 – Land Cover (GLCNMO) Download,” ISCGM, Geographical Survey Institute, Chiba University and collaborating organizations, 18 02 2013. [Online]. Available: http://211.19.49.27/gmd/download/glcnmo.html.

[15] “Shuttle Radar Topography Mission,” Jet Propulsion Laboratory, NASA, 18 02 2013. [Online]. Available: http://www2.jpl.nasa.gov/srtm/.

[16] “NCEP/NCAR Reanalysis dataset,” Earth System Research Laboratory, NOAA, 18 02 2013. [Online]. Available: http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.html.

[17] “Modern Era Reanalysis for Research and Applications (MERRA),” NASA GSFC Global Modelling and Assimilation Office (GMAO), 2008. [Online].

[18] DNV GL, “FOWIND Offshore Wind Speed Mapping of Gujarat and Tamil Nadu,” 2014a.

[19] Bureau of Indian Standards, “Code of Practice for Design Loads for Building and structues”.

[20] National Institute of Disaster Management, [Online]. Available: http://nidm.gov.in/PDF/DP/GUJARAT.PDF. [Accessed Dec 2014].

[21] “Vestas Track record,” [Online]. Available: http://nozebra.ipapercms.dk/Vestas/Communication/Trackrecord. [Accessed February 2014].

[22] EWEA, “The European offshore wind industry - key trends and statistics 2014,” EWEA, 2015.

[23] DNV GL, “Project FORCE - Offshore Wind Cost Reduction Through Integrated Design,” 2014a. [Online]. Available: https://www.dnvgl.com/news/integrated-approach-to-wind-turbine-structure-will-reduce-cost-of-offshore-wind-by-at-least-10--8043. [Accessed 10 03 2015].

[24] DNV GL, “Offshore Wind Cost Reduction Manifesto,” 2014 b. [Online]. Available: https://www.dnvgl.com/energy/brochures/download/offshore-wind-manifesto.html . [Accessed 10 03 2015].

[25] DNV GL , *DNV GL foundation database and experience.*

[26] DNV GL , “Guidelines: Technical Note for the Certification of Wind Turbines for Tropical Cyclones, Revision 0 (pdf-version),” [Online]. Available: http://www.gl-group.com/en/certification/renewables/CertificationGuidelines.php .

[27] DNV, “ Design of Offshore Wind Turbine Structures,” May 2014a. [Online]. Available: http://www.gl-group.com/pdf/DNV-OS-J101_2014-05.pdf. [Accessed 23 04 2015].

[28] IEC, “International Standard IEC 61400-1 Third edition 2005-08,” 2005. [Online]. Available:

http://webstore.iec.ch/preview/info_iec61400-1%7Bed3.0%7Den.pdf.

[29] GL , "Guideline for the Certification of Offshore Wind Turbines - Edition 2012," 2012. [Online]. Available: http://www.gl-group.com/pdf/2012-12_GL_RC_Offshore_Guideline.pdf.

[30] S. S. Merh and L. Chamyal, "Quaternary Geology of Gujarat Alluvial Plains," *Proceedings of Indian National Science Academy,* vol. 63, p. 1–98, 1997.

[31] National Institute of Disaster Management, Gujarat, "NIDM, Gujarat- National Disaster Risk Reduction Portal".

[32] Building Materials & Technology Promotopn Council (BMTPC); India..

[33] K. Kojima, K. Fujita and I. Takewaki, "Unified analysis of kinematic and inertial earthquake pile responses via the single –input response spectrum metho," *Journal of Soil Dynamics and Earthquake Engineerin,* vol. 63., pp. 36-55, 2014.

[34] P. Meymand, *Shaking table scale model tests of nonlinear soilpile-superstructure in soft clay,* Ph.D. thesis Univ.of California, Berkely, CA, 1998.

[35] S. Bhattacharya, "Safety assessment of existing piled foundatons in liquefiable soils against buckling instability," *ISET Journal of Earthquake Technology,* vol. 43, no. 4, pp. 133-147, 2006.

[36] G. C. Bhattacharya, F. K. H. Almeida, Vora and H. Siddiquie, "Subsurface geology off Bombay with Paleoclimatic inferences interpreted from shallow geophysical profiles," *Journal of Coastal Research,* vol. 3, no. 4, pp. 521-530, 1987.

[37] Bureau of Indian Standard (BIS), 1893., *Criteria for Earthquake resistant design of structures.,* BIS, Delhi, 2002.

[38] S. Chopra, D. Kumar, B. K. Rastogi, P. Choudhury and R. B. S. Yadav, "Estimation of seismic hazard in Gujarat region, India," *Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards,* vol. 52, no. ISSN 0921-030X, 2010.

[39] "Wind Energy Facts-Electrical Works," [Online]. Available: http://www.wind-energy-the-facts.org/electrical-works.html. [Accessed 9 Dec 2014].

[40] Crown Estate, "Value breakdown for the offshore wind sector," 2010.

[41] P. Bresesti, W. L. Kling, R. L. Hendriks and R. Vailati, "HVDC connection of offshore windfarms to the transmission system," *IEEE Trans. Energy Convers.,* Vols. vol. 22, no. 1, p. pp. 37–43, 2007.

[42] N. Flourentzou, V. G. Agelidis and G. D. Demetriades, "VSC-based HVDC power transmission systems: An overview,," *IEEE Trans. Power Electron.,* Vols. vol. 24, no. 3, p. pp. 592–602, 2009.

[43] GERC, " Gujarat Electricity Regulatory commission," 2013. [Online]. Available: http://www.gercin.org/draftpdf/en_1358403330.pdf. [Accessed 2014].

[44] GETCO, "Transmission Network Data," 31 March 2013. [Online]. Available: http://getco.co.in/getco_new/pages/tr%20network%20data.php.

[45] "GMB," [Online]. Available: http://www.gmbports.org/.

[46] "GIDB," [Online]. Available: http://www.gidb.org/cms.aspx?content_id=13.

[47] "MoS," New Delhi, 2014.

[48] "Kandla Port trust," [Online]. Available: http://kandlaport.gov.in/infra-stor-facility.php. [Accessed 10th Oct 2014].

[49] MoRTH, "Update on Indian Port Sector," New Delhi, 2013.

[50] Navigant (BTM Consult), "Global Evaluation of Offshore wind shipping opportunity," 2013.

[51] "Ministry of Shipping of India," [Online]. Available: http://shipping.nic.in/.

[52] "Climate of Gujarat," [Online]. Available: http://en.wikipedia.org/wiki/Climate_of_Gujarat. [Accessed 5 November 2014].

[53] "Institute of Shipping Economics and Logistics," [Online]. Available: https://www.isl.org/en/consulting-and-transfer/offshore-wind-power-logistics. [Accessed 5 November 2014].

[54] BVG Associates, "A Guide to an Offshore Wind Farm," BVG Associates, 2010.

[55] EWEA, "European Wind Energy Association," EWEA, 2011. [Online]. Available: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/23420_Offshore_report_web.pdf. [Accessed 6 November 2014].

[56] GL Garrad Hassan (now DNV GL), "A Guide to UK Offshore Wind Operations and Maintenance," Scottish Enterpise an The CROWN ESTATE, 2013.

[57] EWEA, "Where's the money coming from?," 2013a.

[58] NRDC & CEEW, India, "A Second Wind for India's Energy Market:Financing Mechanisms to Support India's National Wind Energy Mission," 2014.

[59] IDFC, "Chapter 5, Private Equity Financing for CleanTech Infrastructure," in *India Infrastructure Report 2010*, 2010.

[60] Nexant, Emergent Ventures & SRC Global, "Financing Renewable Energy in India," 2013.

[61] US AID INDIA & Gov of India MNRE, "Financing Renewable Energy in India:A review of current status and recommendations for innovative mechanisms," 2013.

[62] Bridge to India, "Bankability and Debt Financing for Solar Projects in India," 2013.

[63] Shrimali, D. Nelson and Gireesh, "Finance Mechanisms for Lowering the Cost of Renewable Energy in Rapidly Developing Countries," April 2014. [Online]. Available: http://climatepolicyinitiative.org/wp-content/uploads/2014/01/Finance-Mechanisms-for-Renewable-Energy-in-Emerging-Economies-Slide-Deck.pdf. [Accessed 20 4 2915].

[64] Climate Policy Initiative, "Meeting India's Renewable Energy Targets: The Financing Challenge.," December 2012. [Online]. Available: http://climatepolicyinitiative.org/wp-content/uploads/2012/12/Meeting-Indias-Renewable-Targets-The-Financing-Challenge.pdf. [Accessed 27 04 2015].

[65] MNRE, "Salient Features - Solar Policies," MNRE, New Delhi, 2012.

[66] Government of Tamil Nadu, "Commercial Taxes," 2013.

[67] D. P. Joshi, "Grid connected and Rooftop power in Gujarat," 6 September 2012. [Online]. Available: http://mnre.gov.in/file-manager/UserFiles/presentations-pwc-workshop-06092012/GEDA.pdf. [Accessed 2 November 2013].

[68] Ministry of Finance,GoI, "Guidelines for VGF Financing for PPP Projects," 2006. [Online].

[69] Business Standard, "Odisha urges Centre to allocate funds from NCEF," 2014.

[70] The Hindu Business Line, "Parekh panel for hiking banks' sectoral cap for power sector," 2014.

[71] Economic Times, "IREDA to raise Rs 1,500 crore via tax-free bonds next fiscal," 2014. [Online]. Available: http://articles.economictimes.indiatimes.com/2014-12-17/news/57154471_1_ireda-tax-free-bonds-renewable-energy-development-agency.

[72] Energy and Petrochemicals Department, Government of Gujarat , "Wind Power Policy – 2013," 2013.

[73] Ibis, "Incentives and guidelined for Wind Power Generation in Gujarat," 2013. [Online]. Available: http://wind-power.industry-focus.net/incentivesguidelines-in-gujarat.html. [Accessed 11 3 2015].

[74] Tariff rates from relevent utilities.

[75] DGVCL (Dakshin Gujarat Vij Company Ltd); MGVCL (Madhya Gujarat Voj Compant Ltd); UGVCL (Uttter Gujarat Vij Company Ltd); PGVCL (Paschim Gujarat Vij Company Ltd);, "Tarrif orders of respective unitlities," 2014.

[76] CDM, "CDM benefits," Clean Development Mechanism, 2015. [Online]. Available: http://cdm.unfccc.int/about/dev_ben/index.html. [Accessed 18 02 2015].

[77] Special Investment Regions, Sector Profile, Vibrant Gujarat, 2011, iNDEXTb, Government of Gujarat, *Special Investment Regions, Sector Profile, 2011,* Gujarat: iNDEXTb, Government of Gujarat.

[78] CROWN ESTATE , "Offshore wind cost reduction: Pathways study.," May 2012. [Online]. Available: http://www.thecrownestate.co.uk/media/5493/ei-offshore-wind-cost-reduction-pathways-study.pdf. [Accessed 27 04 2015].

[79] FOWIND, "Offshore Wind Policy Assessment Report," 2014.

[80] Centre for Science and Environment, "EIA Guidelines Wind Power," New Delhi, 2013.

[81] Galloper Wind Farm Limited, "Galloper Wind Farm Application and Reqirement Documents," 2014. [Online]. Available: http://www.galloperwindfarm.com/application-documents. [Accessed 16 04 2015].

[82] RAVE, Fraunhofer Institute of Wind Energy and Energy System Technology IWES,, "Research at Alpha Ventus, the Research Initiative at the First German Offshore Wind farm," Germany, 2010.

[83] Danish Energy Authority, *Offshore Wind farms and the Environment, Danish Experiences from Horns Rev and Nysted,* Danish Energy Authority, 2006.

[84] Gujarat Ecological Commission, Gandhinagar, "Draft Detailed Project Report for component :A, Coastal resources conservation & management- Mangrove Restoration & Coral transplantation Project," Gujarat Ecological Commission (GEC), Gandhiinagar, Gandhinagar, 2009.

[85] Gujarat Ecological Commission, *Coral Reefs in Kutch,* 2009a.

[86] MoEF, "THE WILDLIFE (PROTECTION) ACT, 1972," 1972. [Online]. Available: http://www.moef.nic.in/legis/wildlife/wildlife1c1.pdf.

[87] P. Kannan, S. Venkatesan, M. Rajagopalan and E. Vivekanandan, "Strandings of Green Turtles along the Saurashtra Coast, Gujarat, India," Marine Turtle Newsletter, 2005. [Online]. Available: http://www.seaturtle.org/mtn/archives/mtn110/mtn110p4.shtml.

[88] Clean Development Mechanism (CDM), "Tool to calculate the emission factor for an electricity system. Version 4.," 2013. [Online]. Available: http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v4.0.pdf/history_view.

[89] Central Electricity Authority GoI, "BASELINE CARBON DIOXIDE EMISSIONS FROM POWER SECTOR," [Online]. Available: http://cea.nic.in/reports/planning/cdm_CO2/cdm_CO2.htm.

[90] GWEC, "Global Wind Report - Annual MArket Update 2013," Global Wind Energy Council, 2013.

[91] NAGA, "NAGA, WorldFish Center Quarterly Vol. 27 No. 3 & 4 Jul-Dec 2004," http://www.worldfishcenter.org/Naga/naga27-3n4/pdf/article03.pdf , 2004.

[92] MINISTRY OF ENVIRONMENT AND FORESTS, "EIA Notification," Gazette of India ,Extraordinary, Part-II, and Section 3, Sub-section (ii), 2006.

[93] MINISTRY OF ENVIRONMENT AND FORESTS (Department of Environment, Forests and Wildlife), "COASTAL REGULATION ZONE NOTIFICATION," Gazette of India,Extraordinary, Part-II, Section 3, Sub-section (ii) of dated the 6th January, 2011), 2011.

[94] Ministry of Law and Justice, *The Right to fair compensation and transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013,* New Delhi, 2013.

[95] Government of Gujarat, "The Gujarat Town Planning and Urban Development Act, 1976," The Gujarat Government Gazette , 1976.

[96] MINISTRY OF ENVIRONMENT & FORESTS , "Environmental (Protection) Act, 1986," Government of India, New Delhi, 1986.

[97] Ministry of Environment & Forests GOVERNMENT OF INDIA, NEW DELHI, "Environmental Impact Assessment Guidance Manual Ports and Harbors," 2009.

[98] Ministry of Tribal Affairs, GoI, *The Scheduled tribes and other traditional forest dwellers (Recognition of forest rights) Act, 2006 and Forest Rules, 2007,* New Delhi, 2007.

[99] Ministry of Labour and Employment, GoI, New Delhi.

[100] Ministry of Environment and Forest, GoI, New Delhi.

[101] C. J. Crabtree, "Operational and reliability analysis of offshore wind farms - has availability gone with the wind?," in *EWEA 2012*, Copenhagen, April 2012.

[102] Energy numbers, "Energy numbers," 15 April 2014. [Online]. Available: http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms. [Accessed April 2015].

[103] UK Government , "Renewable sources of energy," [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337684/chapter_6.pdf.

[104] Navigant , "Offshore Wind Market and Economic Analysis," 2013.

[105] EWEA, "The European offshore wind industry - key trends and statistics," 2013b.

[106] Navigant, "Offshore Wind Market and Economic Analysis: Annual Market Assessment prepared for US Deparntment of Energy," 2013a.

[107] DNV GL, *Gujarat Offshore Wind Potential Development Zones for Pre-feasibility Study,* 2014.

[108] Roland Berger, "Offshore Wind Toward 2020," 2013. [Online]. Available: http://www.rolandberger.com/media/pdf/Roland_Berger_Offshore_Wind_Study_20130506.pdf.

[109] Upwind, "Design Limits and Solutions for very large turbines," in *European Commission, Sixth Framework Programme*, 2011.

[110] W. Musial and B. Ram, Large Scale Offshore Wind Power in the US: Assessment of Opportunities and Barriers, NREL, 2010.

[111] Navigant Consulting , "US Offshore Wind Manufacturing and Supply Chain Development," 2013.

[112] Batelle, "2014 Global R&D and Funding Forecast," 2014.

[113] Planning Commission, Government of India, "Technology & Depth Recommendations and Implementations Plan ,XII Five Year Plan," 2012. [Online]. Available:

http://planningcommission.gov.in/reports/genrep/rep_cluster2509.pdf.

[114] Department of Science and Technology, "Research and Development Stastistics at a Glance (2011-12)," 2013. [Online]. Available: http://www.nstmis-dst.org/pdf/finalrndstatisticsataglance2011121.pdf.

[115] Department of Science and Technology, "Stimulation of Investment of Private Sector into Research and Development in India," 2013. [Online]. Available: http://dst.gov.in/white-paper.pdf.

[116] PwC, "New guidelines for approval of in-house R&D centres and submission of report under section35(2AB) issued," 2014. [Online]. Available: http://www.pwc.in/assets/pdfs/news-alert-tax/2014/pwc_news_alert_24_june_2014_new_guidelines_issued_for_approval_of_in-house_randd_centres.pdf.

[117] Press Information Bureau, Government of India, "Creation of National Clean Energy Fund," 2011. [Online]. Available: http://pib.nic.in/newsite/erelease.aspx?relid=71517.

[118] Department of Science & Technology, "Technology Development Board," 2009. [Online]. Available: http://www.tdb.gov.in/WebContent.aspx?id=8&type=homemore. [Accessed 15 October 2013].

[119] TIFAC, 2009. [Online]. Available: http://www.tifac.org.in/index.php?option=com_content&view=article&id=29&Itemid=41. [Accessed Oct 2013].

[120] G. E. Dieter, Assessment of Research Needs for Wind Turbine Rotor Materials Technology, Washington D.C : National Academy Press, 1991.

[121] EWEA, "Winds in our Sails," 2011.

[122] WISE, "Action Plan for Comprehensive RE Development in Tamil Nadu," 2012.

[123] ILO, "Research Brief: Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up.," 2011.

[124] Government of Gujarat, *Proposal of Convergence of NAP & NREGA in Kachchh district: Gujarat,* Gujarat.

[125] Gujarat Ecological Commission, "Draft Detailed Project Report for component :A, Coastal resources conservation & management- Mangrove Restoration & Coral transplantation Project," Gujarat Ecological Commission (GEC), Gandhiinagar, Gandhinagar, 2009.

[126] Gujarat State Disaster Management Authority (GSDSMA), Gandhinagar, "Gujarat Hazard Risk & Vulnerability Assessment Atlas (GHRVA), GSDMA, 2005," GSDMA, Gandhinagar, 2005.

[127] 4coffshore.com, "News: 4coffshore," 19 December 2014. [Online]. Available: http://www.4coffshore.com/windfarms/burbo-bank-goes-for-v164-8.0-mw-from-mhi-vestas-nid1115.html. [Accessed 22 Deceber 2014].

[128] EWEA, "The European offshore wind industry -key trends and statistics 1st half 2014," EWEA, 2014.

[129] EWEA, "The European offshore wind industry - key trends and statistics 2011," EWEA, 2012.

[130] EWEA, "The European offshore wind industry - key trends and statistics 2012," EWEA, 2013.

[131] EWEA, "The European offshore wind industry - key trends and statistics Midyear 2014," EWEA, July 2014.

[132] E.ON, "E.ON Wind Turbine Technology and Operations Factbook," E.ON, 2013.

[133] NREL, "Large-Scale Offshore Wind Power in the Wind Assessment of Opportunities and Barriers," NREL, 2010.

[134] T. Burton, N. Jenkins, D. Shrape and E. Bossanyi, Wind Energy Handbook, Wiley, 2011.

[135] P. Jain, Wind Energy Engineering, The McGraw Hill Companies, 2011.

[136] European Enviroment Agency, "Europe's onshore and offshore wind energy potential An assessment of environmental and economic constraints," European Enviroment Agency, 2009.

[137] GSDMA, "Gujarat Hazard Risk & Vulnerability Assessment Atlas (GHRVA), GSDMA, 2005.," Gujarat State Disaster Management Authority (GSDSMA), Gandhinagar., Gandhinagar, 2005.

[138] "Borkum West II," [Online]. Available: http://www.wagenborg.com/our-stories/borkum-west-ii.

[139] [Online]. Available: http://www.windlifter.nl/.

[140] "World Maritime News," [Online]. Available: http://worldmaritimenews.com/wp-content/uploads/2013/11/Alstoms-Haliade-Installation-Successfully-Completed.jpg.

[141] "Renewbl.com," [Online]. Available: http://www.renewbl.com/page/245.

[142] DNV GL, *Gujarat offshore wind potential development zones for pre-feasibility study,* 2014.

[143] Power Cluster, "Overcoming Challenges for the Offshore Wind Industry and Learning From the Oil and Gas industry," 2011.

[144] EWEA, "Oceans of Opportunity," 2009.

[145] European Union, "DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," 23 April 2009. [Online]. Available: http://www.ewea.org/fileadmin/ewea_documents/documents/00_POLICY_document/RES_Directive_special.pdf.

[146] BNEF, "Global Trends in Renewable Energy Investment," Bloomberg New Energy Finance, 2014.

[147] CERC, "Determination of forbearance and floor price for Solar REC," 2014.

[148] GERC, "Procurement of Energy from Renewable Sources (First Amendment)," 2014. [Online]. Available: http://www.gercin.org/regulations_amendmentpdf/en_1394007948.pdf.

[149] IEX, "Renewable Energy Certificate Market Data," 2014. [Online]. Available: http://www.iexindia.com/marketdata/recdata.aspx.

[150] KPMG, "Offshore Wind in Europe - 2010 Market Report," KPMG , 2010.

[151] GoI MNRE & Partnership to Advance Clean Energy - Deployment (PACE - D) Technical Assistance Program, "Financing Renewable Energy in India: A review of current status and recommendations for innovative mechanisms.," Nexant, Inc. , 2013.

[152] ""Anemoscope User's Guide", Canadian Hydraulics Centre and Environment Canada; http://www.anemoscope.ca/Documents/AnemoScope_User_Guide.pdf, accessed 18/05/2013.," [Online].

[153] EWEA, "The European offshore wind industry - key trends and statistics 2014," European Wind Energy Agency, 2015.

[154] WindPower Offshore, "Costs force ABB to abandon offshore converter work," 19 11 2014. [Online]. Available: http://www.windpoweroffshore.com/article/1322618/costs-force-abb-abandon-offshore-converter-work. [Accessed 10 03 2015].

[155] WindPower Offshore, "Siemens looks to recover offshore wind HVDC losses," 27 01 2015. [Online]. Available: http://www.windpoweroffshore.com/article/1331191/siemens-looks-recover-offshore-wind-hvdc-losses?DCMP=EMC-CONWindpowerOffshoreWeekly&bulletin=windpower-offshore-weekly. [Accessed 10 03 2015].

[156] DNV GL Energy, *Power Frequency Optimisation for offshore wind farms,,* 2014b.

[157] Press Information Bureau Government of India MNRE, "MOU Signed for First Ever Offshore Wind Power Project in India," 01 October 2014. [Online]. Available: http://pib.nic.in/newsite/PrintRelease.aspx?relid=110186 . [Accessed 15 04 2015].

[158] EWEA, "Where's the money coming from? Financing offshore wind farms," November 2013. [Online]. Available: http://www.ewea.org/fileadmin/files/library/publications/reports/Financing_Offshore_Wind_Farms.pdf. [Accessed 27 04 2015].

[159] "Anemoscope Reference Guide", Canadian Hydraulics Centre and Environment Canada; http://www.anemoscope.ca/Documents/AnemoScope_ReferenceGuide.pdf, accessed 18/02/2013.," [Online].

[160] S. D. Attri and A. Tyagi, "Climate profile of India," Indian Meteorological Department, 2010.

[161] V. Gevorgian, "Submarine Power Transmissions," in *Leading the Caribbean to a sustainable energy future*, 2010.

References - Gujarat Offshore Wind Potential Development zones (see Section 4)

a. DNV GL, "Constraints Data Status - Gujarat", October 17 2014.

b. General Bathymetric Chart of the Oceans (GEBCO), "Gridded bathymetry data", 2014, [on line] http://www.gebco.net/data_and_products/gridded_bathymetry_data/

c. Gujarat Maritime Board, "Ports in Gujarat", 2014, [on line] http://www.gmbports.org/showpage.aspx?contentid=1266

d. OpenStreetMap, 2014, [on line] http://www.openstreetmap.org

e. Maritime and Coastguard Agency (MCA) "Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues", United Kingdom, 2008, [on line] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/282200/mgn371.pdf

f. IMaRS-USF (Institute for Marine Remote Sensing-University of South Florida) (2005). Millennium Coral Reef Mapping Project. Unvalidated maps. These maps are unendorsed by IRD, but were further interpreted by UNEP World Conservation Monitoring Centre. Cambridge (UK): UNEP World Conservation Monitoring Centre

g. IMaRS-USF, IRD (Institut de Recherche pour le Development) (2005). Millennium Coral Reef Mapping Project. Validated maps. Cambridge (UK): UNEP World Conservation Monitoring Centre

h. Spalding MD, Ravilious C, Green EP (2001). World Atlas of Coral Reefs. Berkeley (California, USA): The University of California Press. 436 pp.

i. UNEP-WCMC, WorldFish Centre, WRI, TNC (2010). Global distribution of warm-water coral reefs, compiled from multiple sources (listed in "Coral_Source.mdb"), and including IMaRS-USF and IRD (2005), IMaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: data.unep-wcmc.org/datasets/13

j. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011a). Global distribution of mangroves forests of the world using earth observation satellite data. In Supplement to: Giri et al. (2011b). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: data.unep-wcmc.org/datasets/21

k. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011b). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20: 154-159

l. Spalding M, Kainuma M, Collins L (2010a). World Atlas of Mangroves. A collaborative project of ITTO, ISME, FAO, UNEP-WCMC, UNESCO-MAB, UNU-INWEH and TNC. London (UK): Earthscan, London. 319 pp.

m. Spalding M, Kainuma M, Collins L (2010b). Data layer from the World Atlas of Mangroves. In Supplement to: Spalding et al. (2010a). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: data.unep-wcmc.org/datasets/22

n. IUCN, UNEP-WCMC (2014). The World Database on Protected Areas (WDPA). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: www.protectedplanet.net

o. UNEP-WCMC (2012). Data standards for the World Database on Protected Areas. Cambridge (UK): UNEP World Conservation Monitoring Centre. 15 pp.

p. International Chart Series, "Gulf of Kachchh", scale: 1: 150 000

q. International Chart Series, "Sir Creek to Dwarka", scale: 1: 300 000

r. International Chart Series, “Okha to Veraval”, scale: 1: 300 000

s. International Chart Series, “Veraval to Pipavav”, scale: 1: 300 000

t. International Chart Series, “Approaches to Gulf of Khambhat”, scale: 1: 300 000

u. International Chart Series, “Approaches to Mumbai”, scale: 1: 300 000

v. Wikipedia (2006), File : India earthquake zone map en.svg, [on line], http://commons.wikimedia.org/wiki/File:India_earthquake_zone_map_en.svg#metadata

w. Divins, D.L., Total Sediment Thickness of the World's Oceans & Marginal Seas, NOAA National Geophysical Data Center, Boulder, CO, 2003.

APPENDIX 1
SELECTION OF STUDY AREA

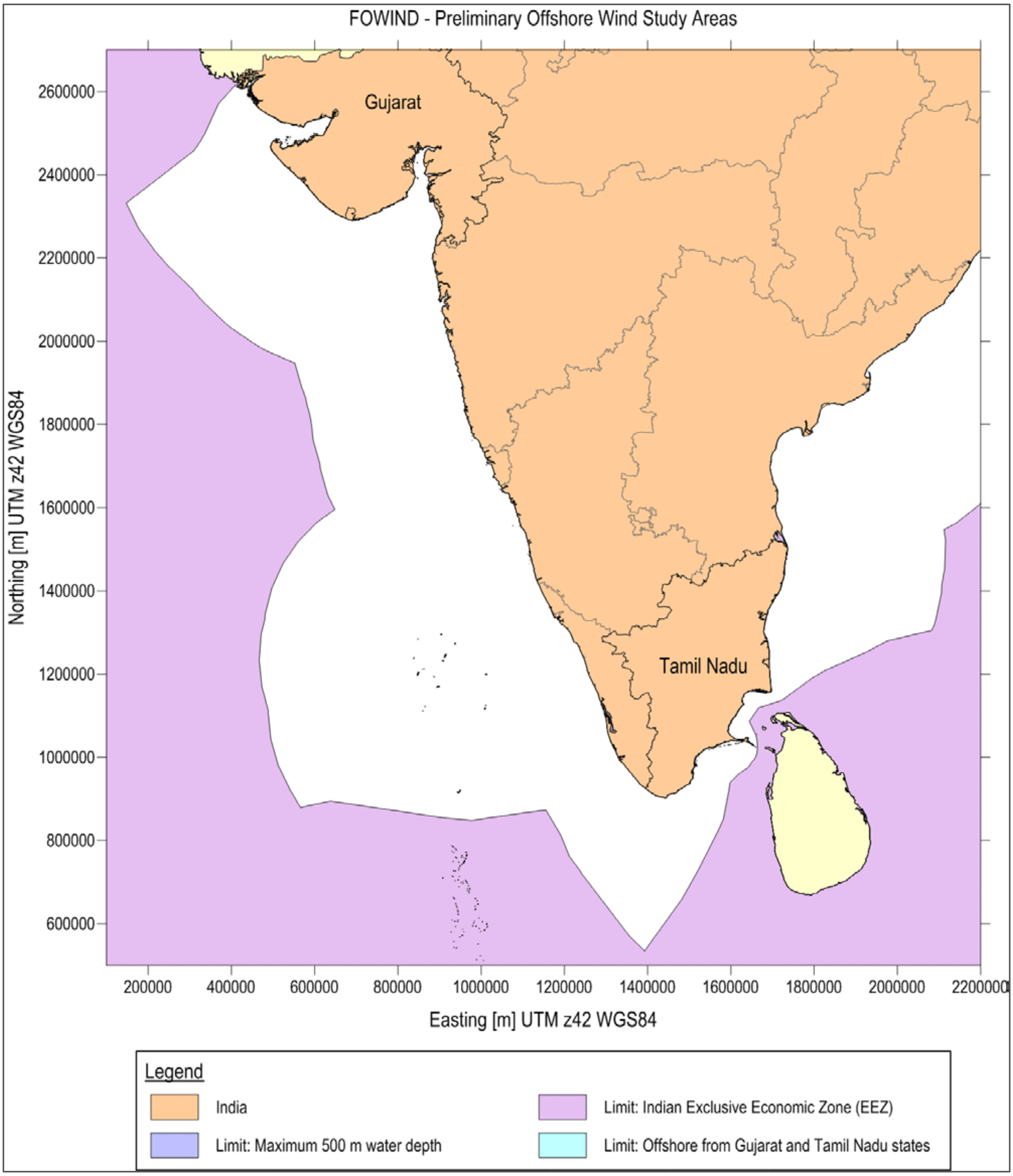


Figure 32: Preliminary limit for offshore wind development - Indian maritime boundary

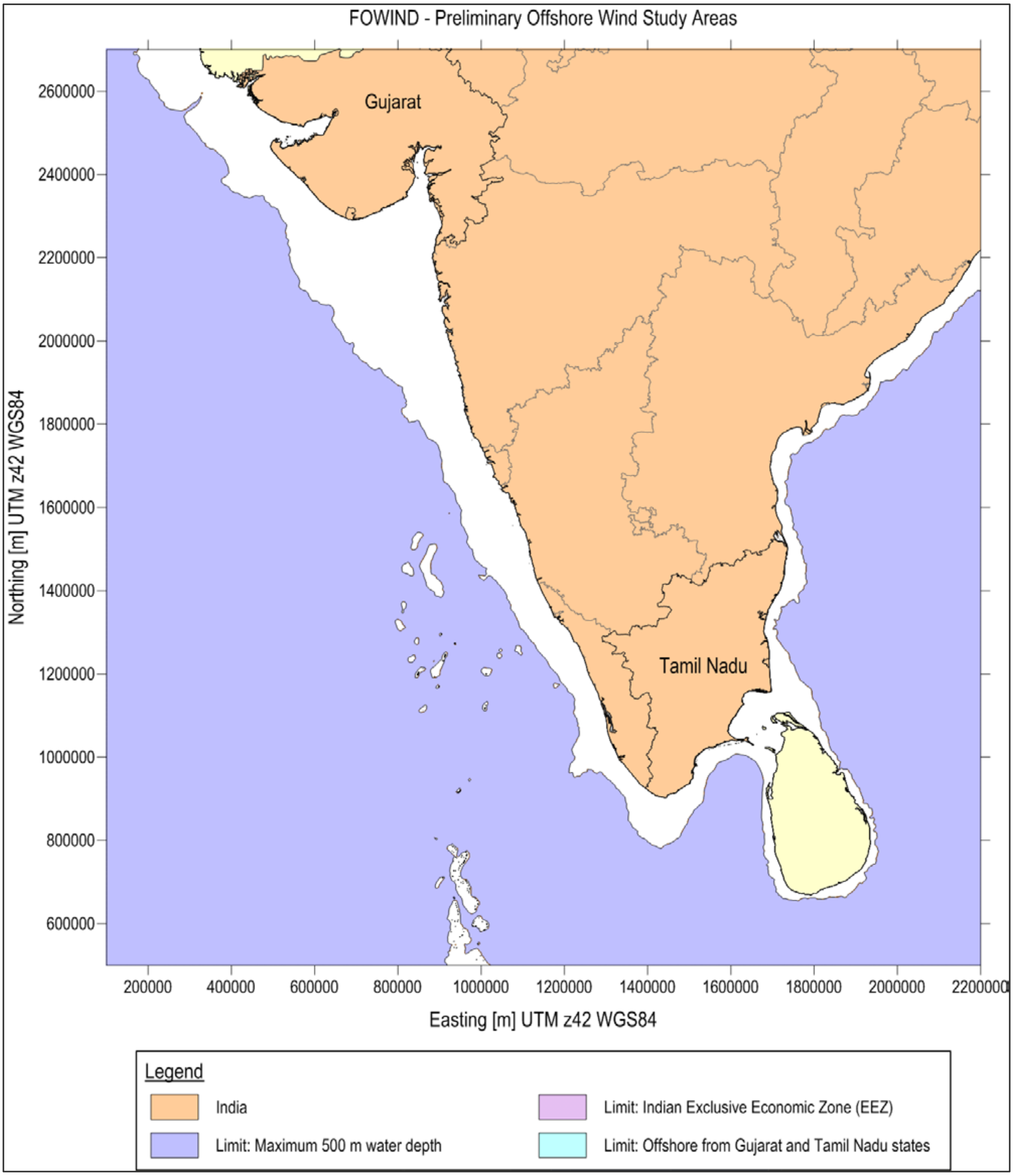


Figure 33: Preliminary limit for offshore wind development – 500 m maximum water depth

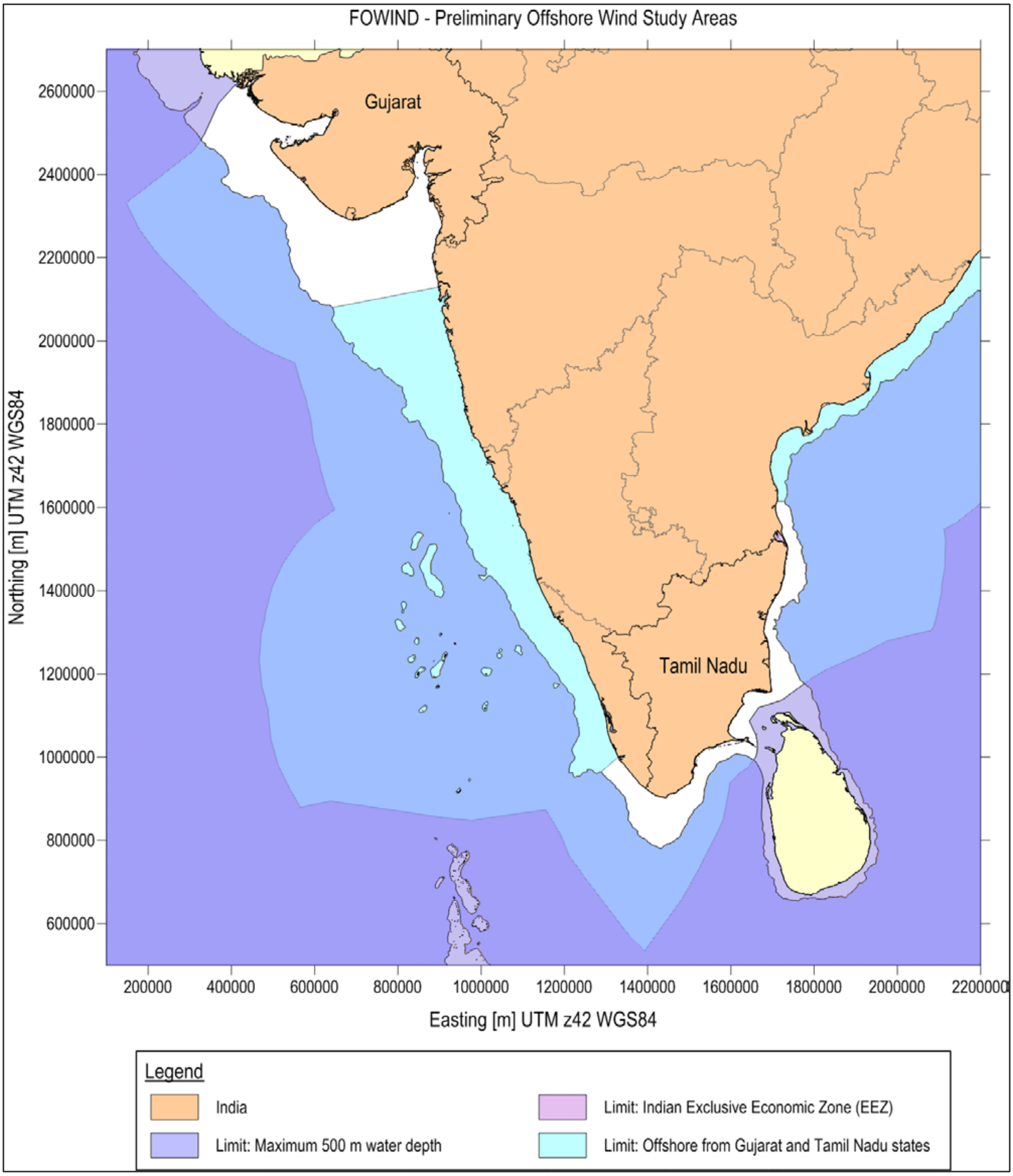


Figure 34: Preliminary limit for offshore wind development - Preliminary constraints combined

APPENDIX 2
MODELLED WIND SPEEDS

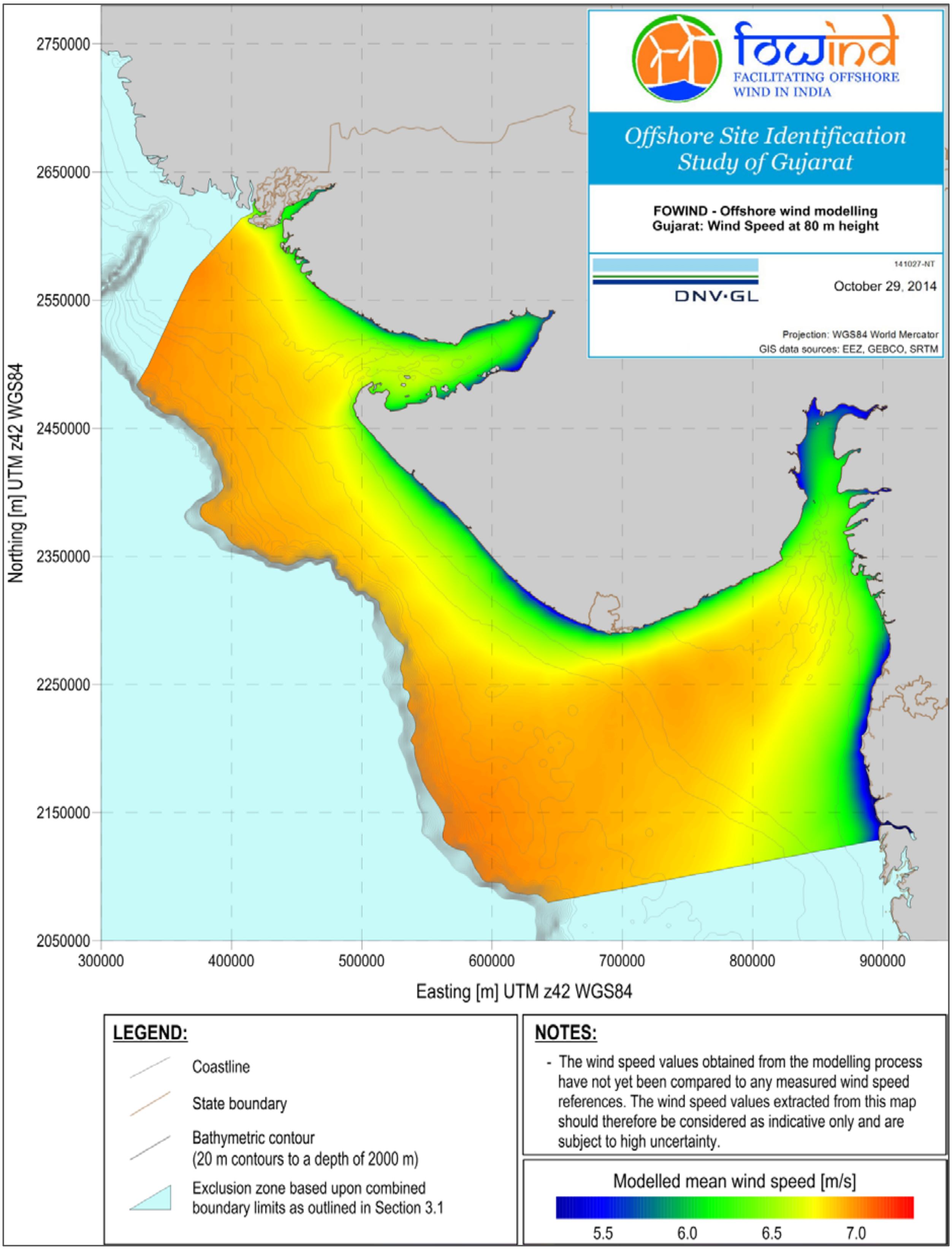


Figure 35: Modelled wind speed over Gujarat at 80 m above sea level

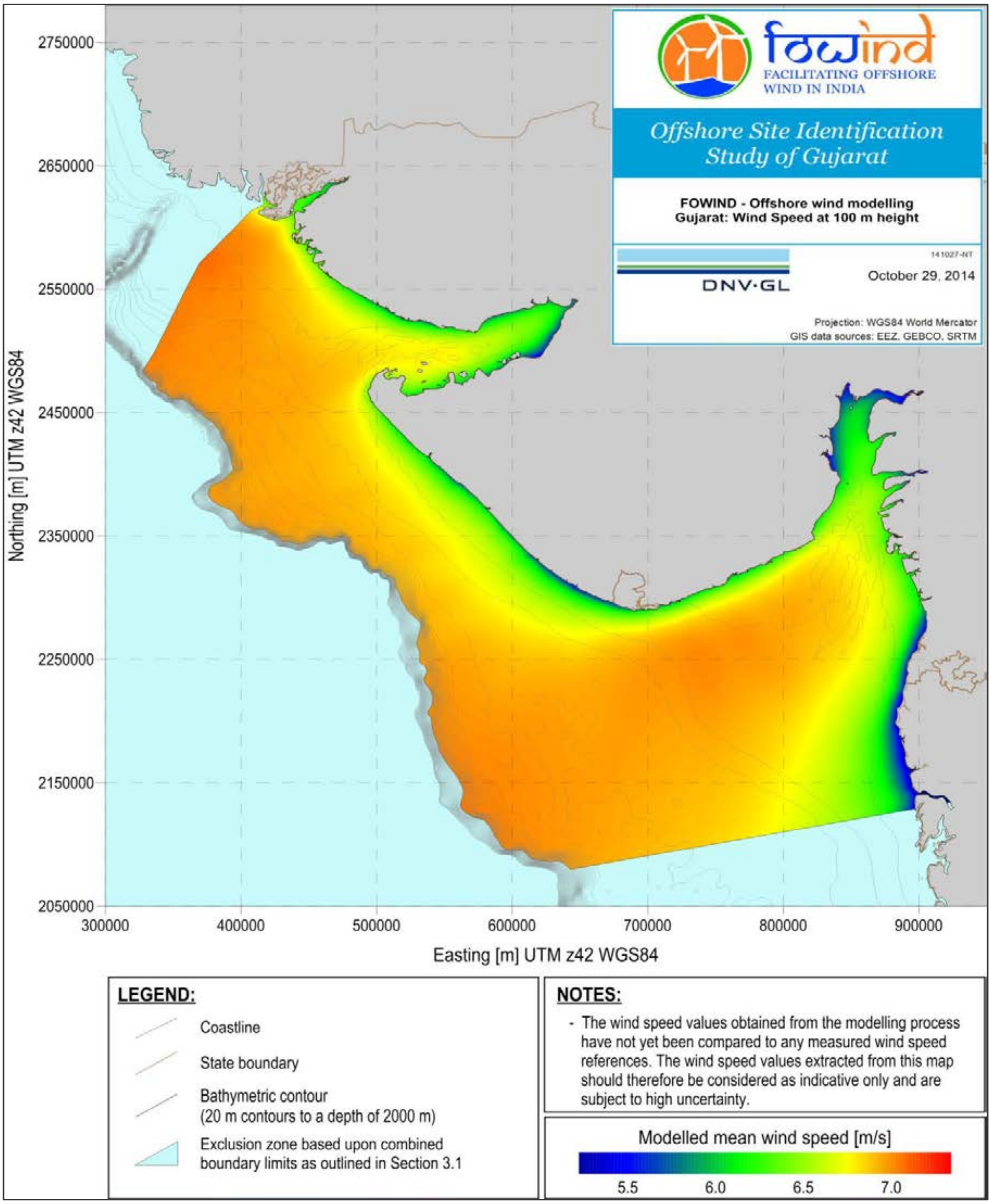


Figure 36: Modelled wind speed over Gujarat at 100 m above sea level

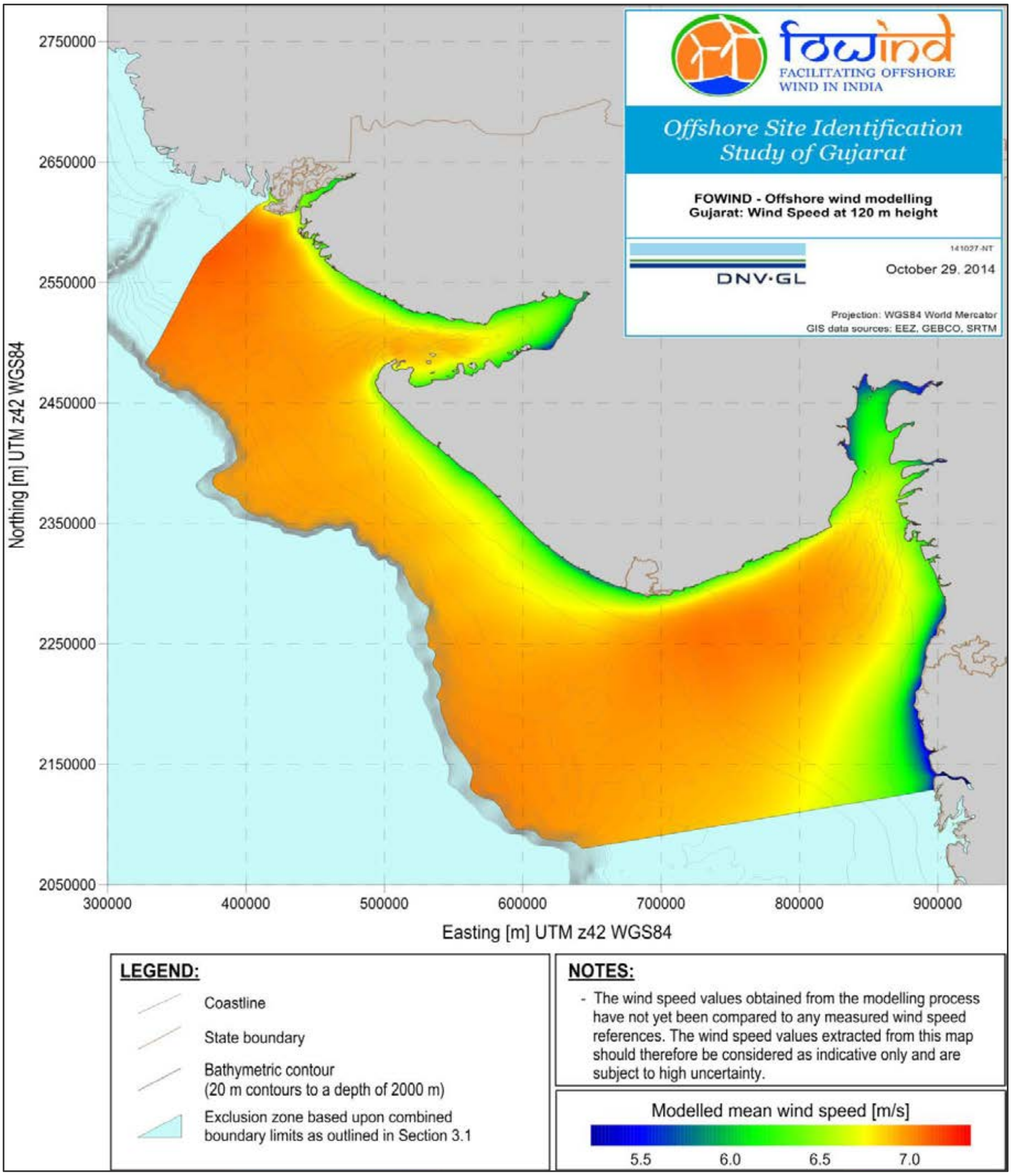


Figure 37: Modelled wind speed over Gujarat at 120 m above sea level

APPENDIX 3

HEAT MAPS WEIGHTING OF SPATIAL INFLUENCES

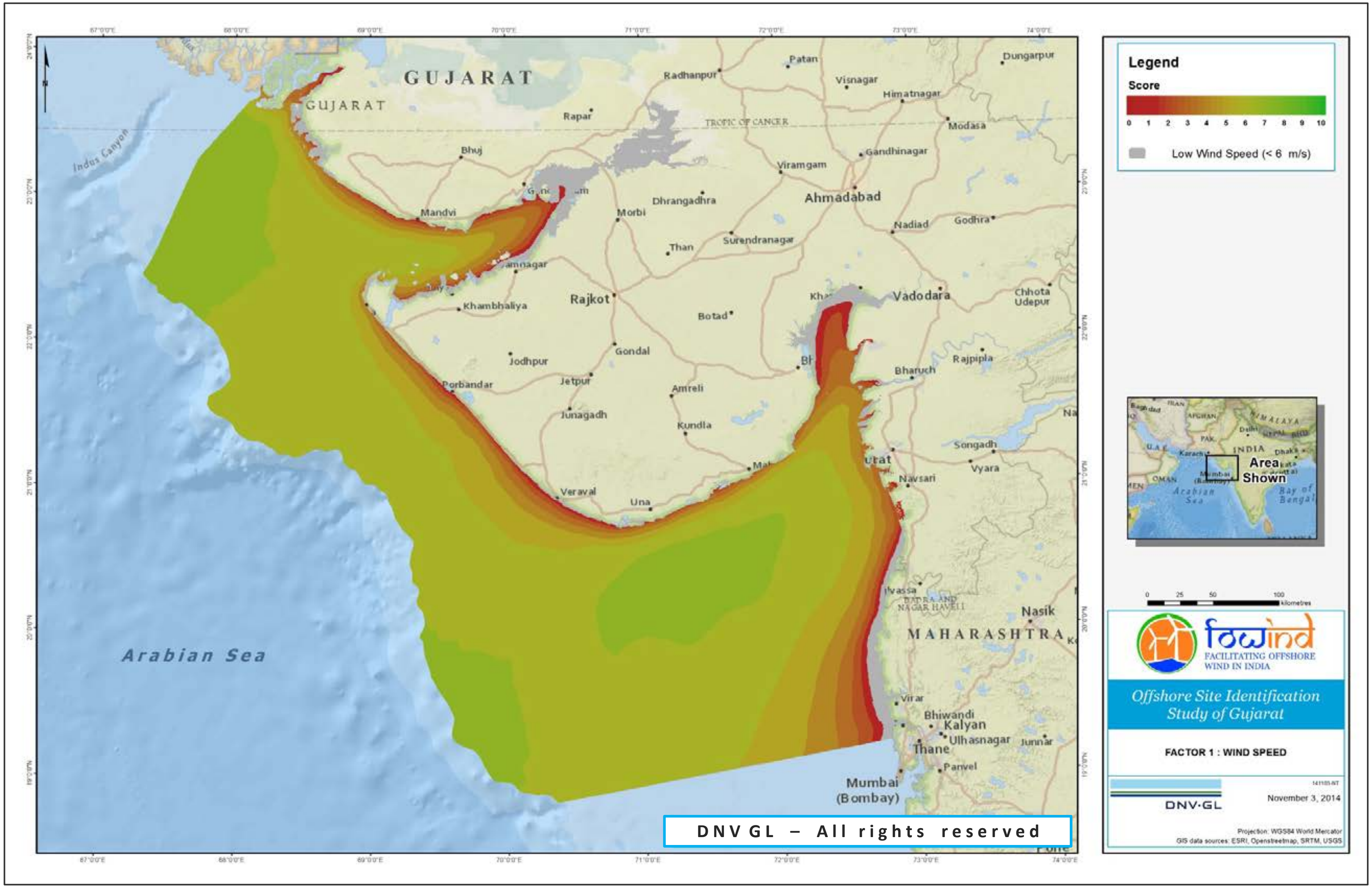


Figure 38: Offshore Wind Speed Heat Map Gujarat

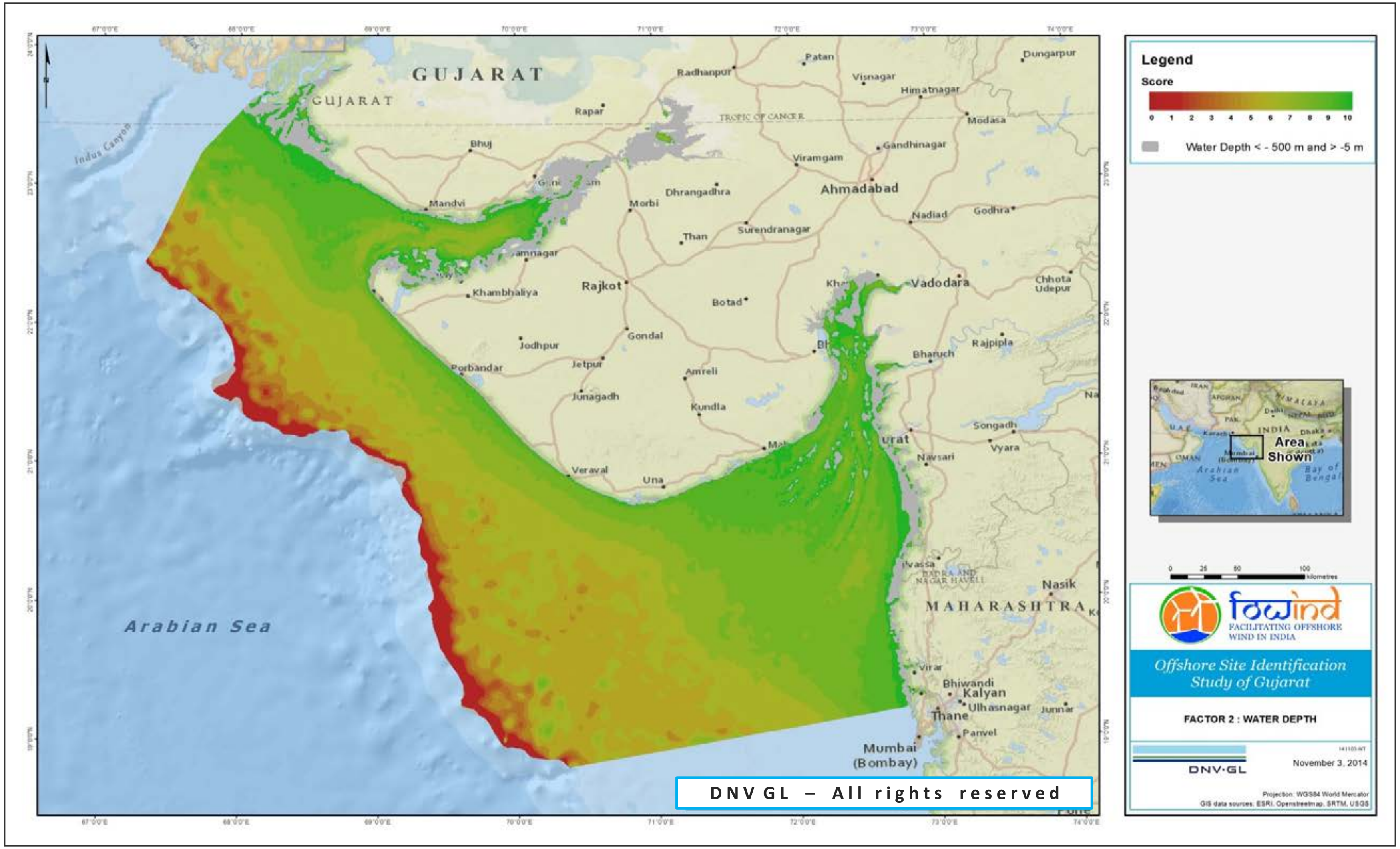


Figure 39: Offshore Water Depth Heat Map Gujarat

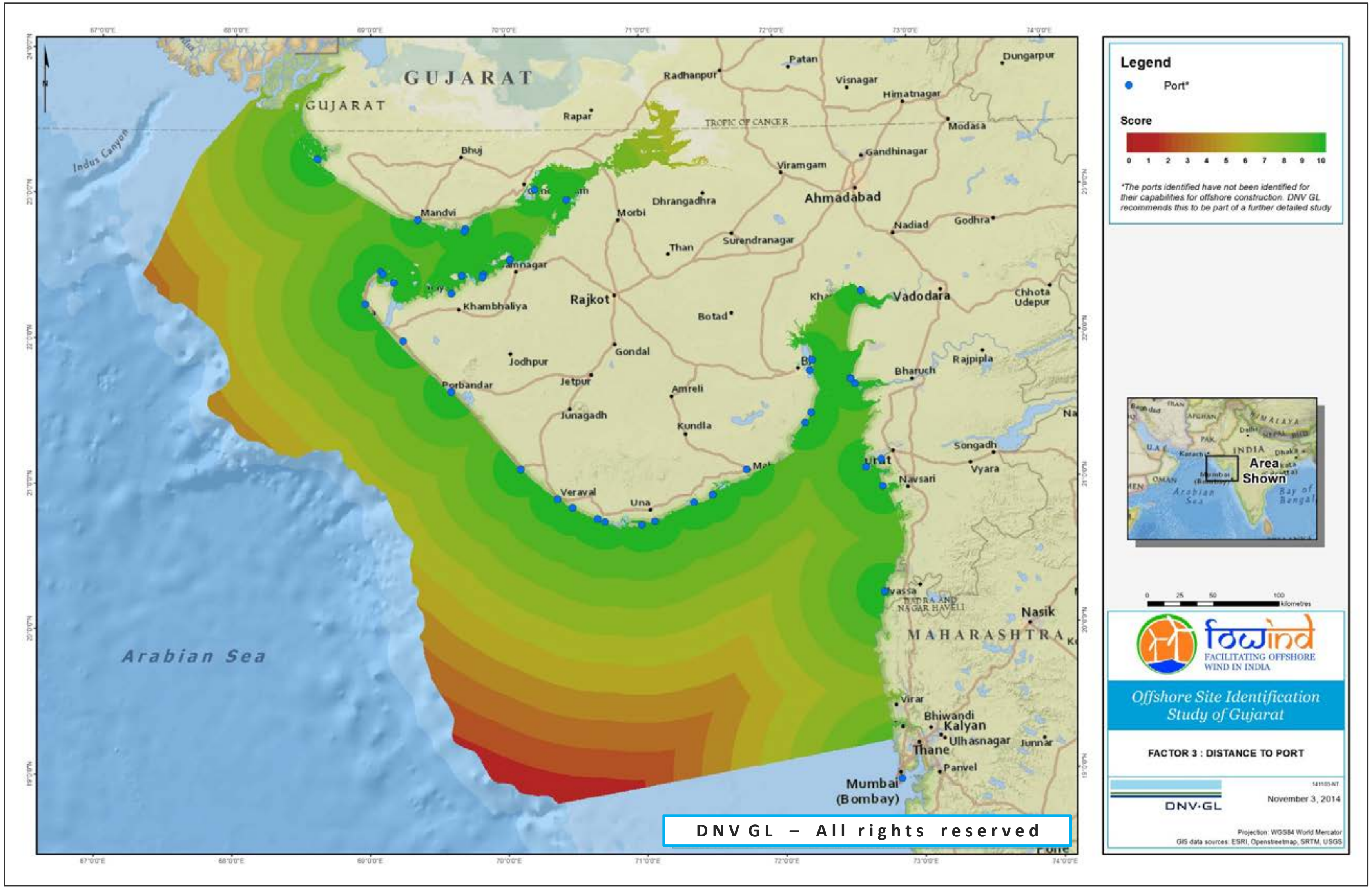


Figure 40: Offshore Port Heat Map Gujarat

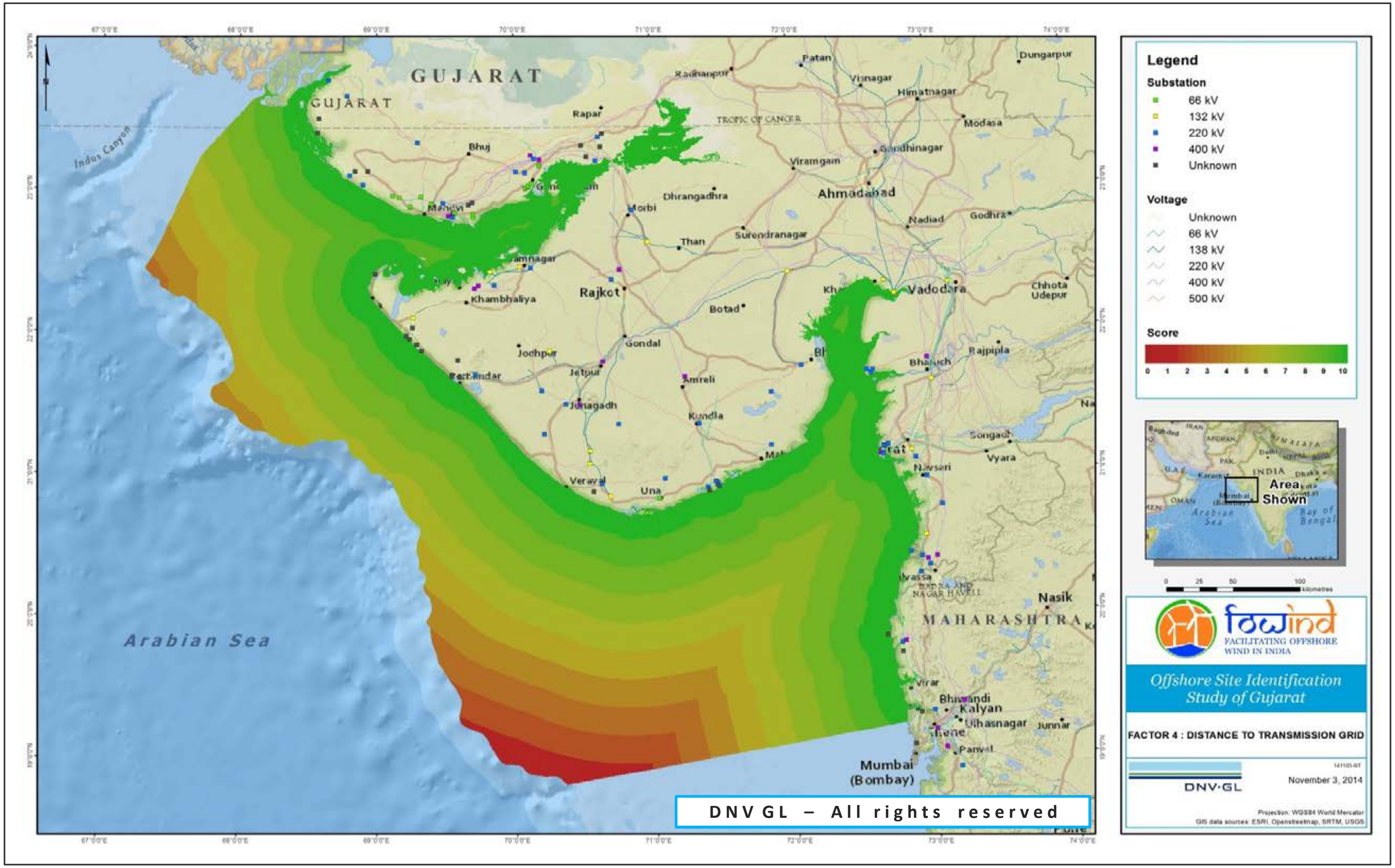


Figure 41: Offshore Grid Heat Map Gujarat

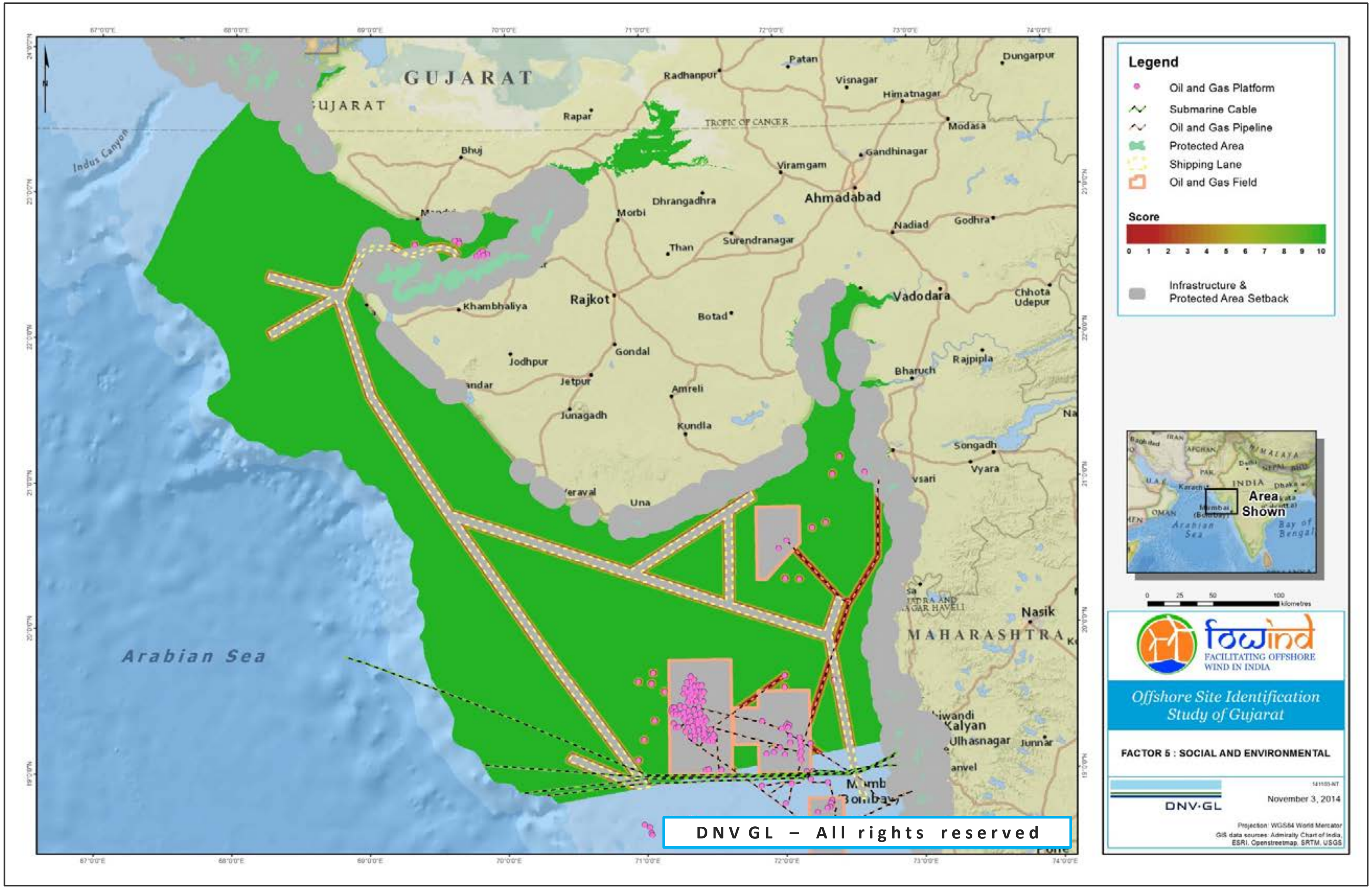


Figure 42: Offshore Social Environment Heat Map Gujarat

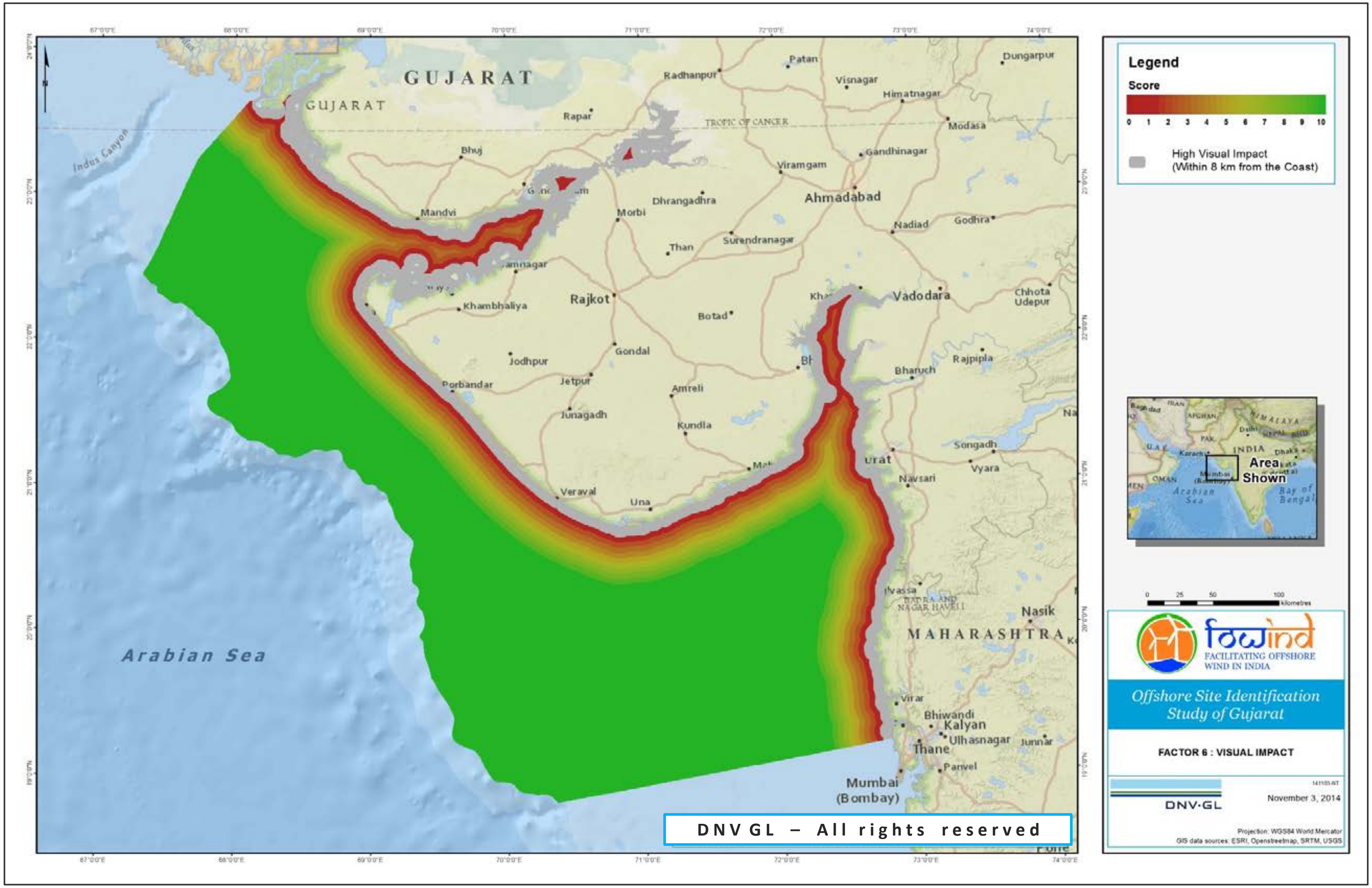


Figure 43: Offshore Visual Impact Heat Map Gujarat

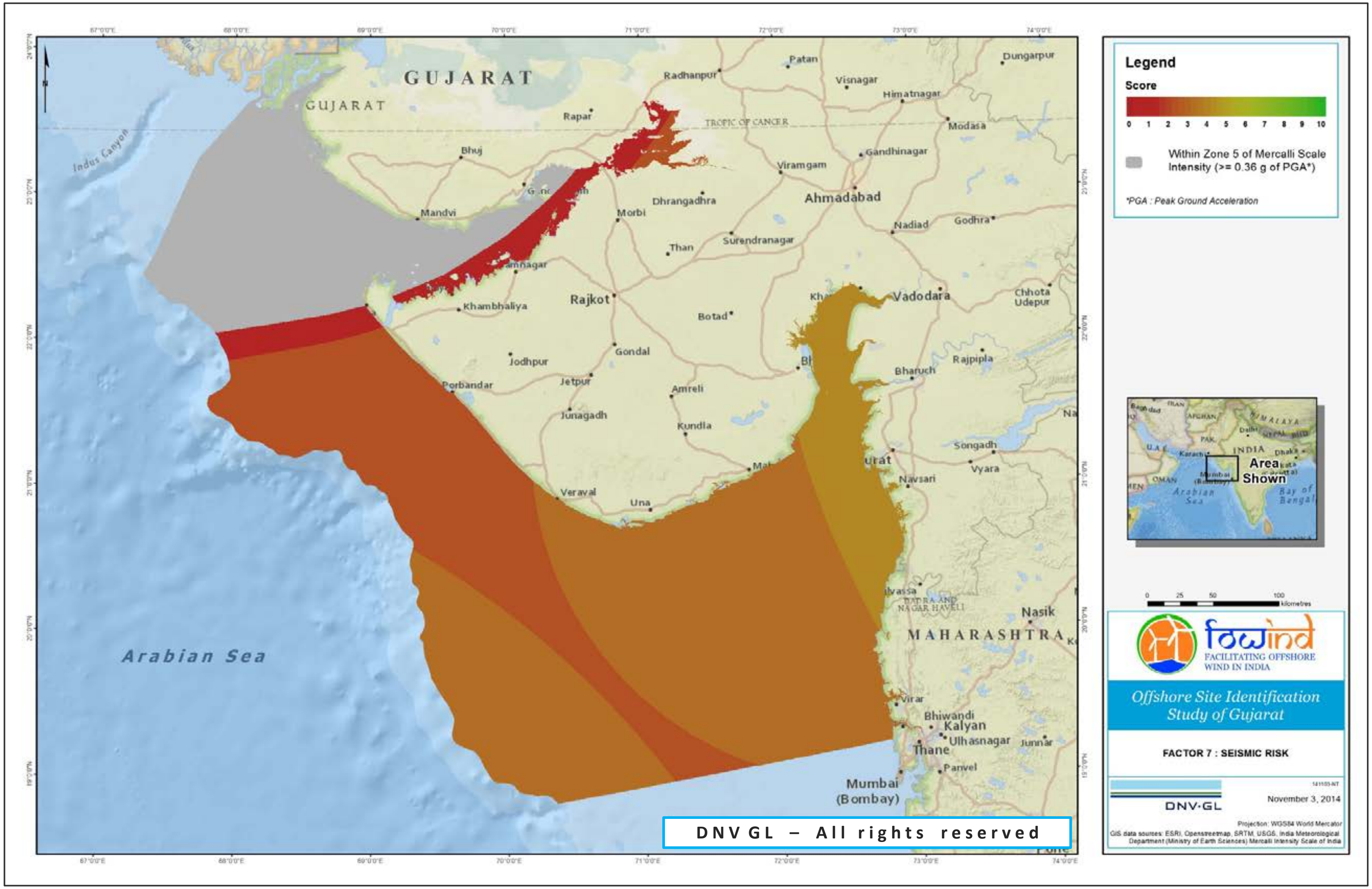


Figure 44: Offshore Seismic Risk Heat Map Gujarat

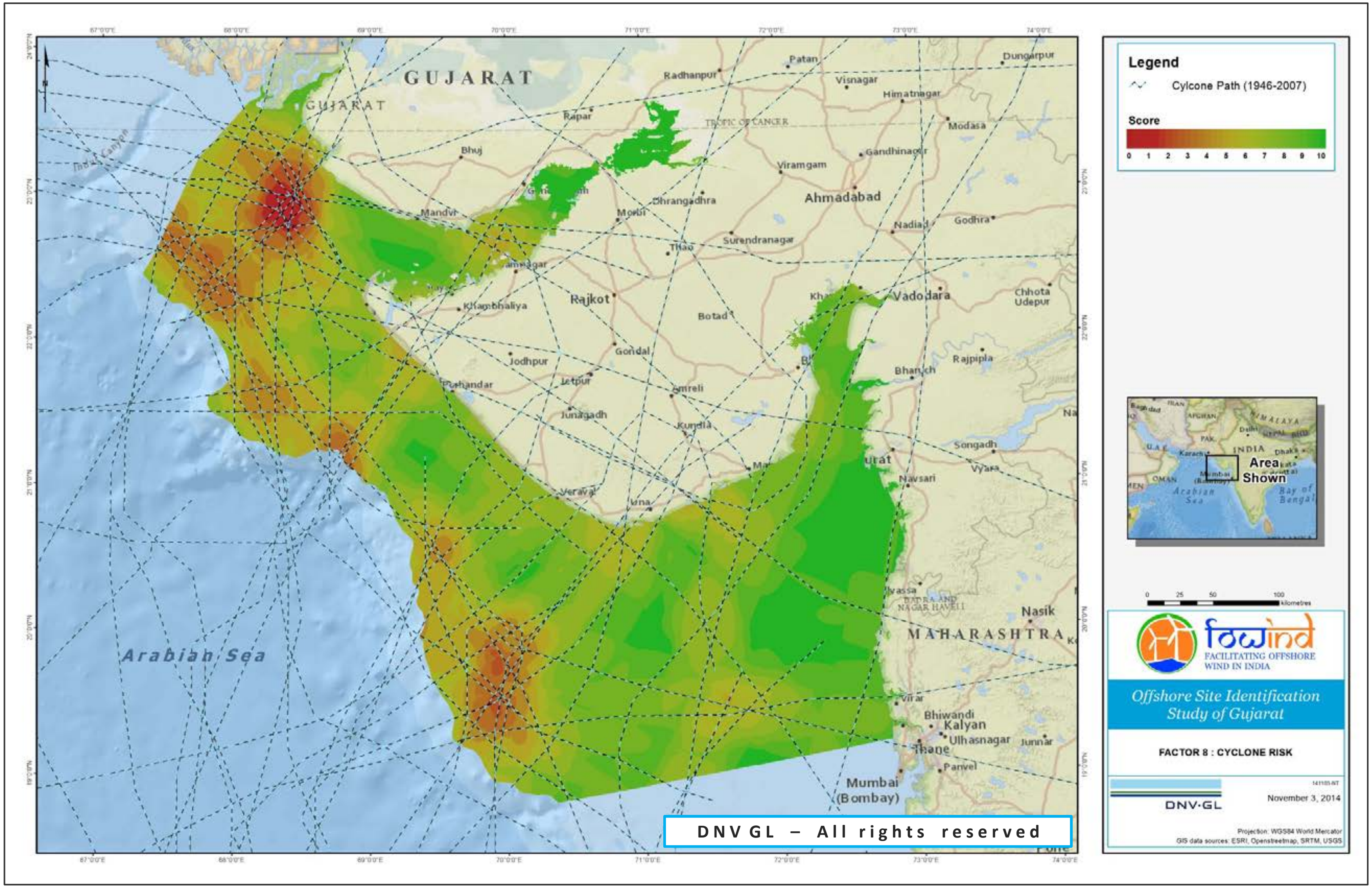


Figure 45: Offshore Cyclone Risk Heat Map Gujarat

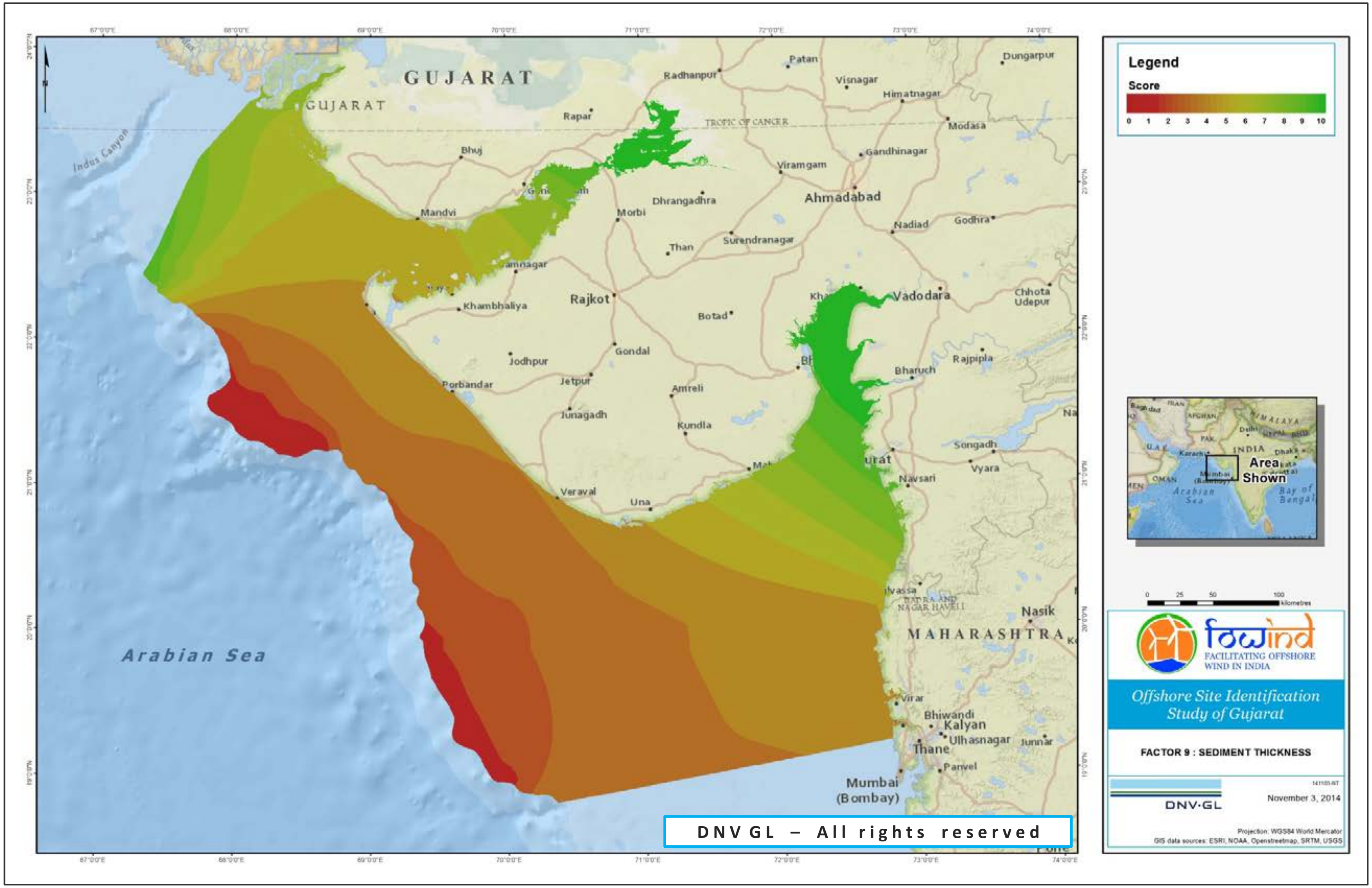


Figure 46: Offshore Sediment Thickness Heat Map Gujarat

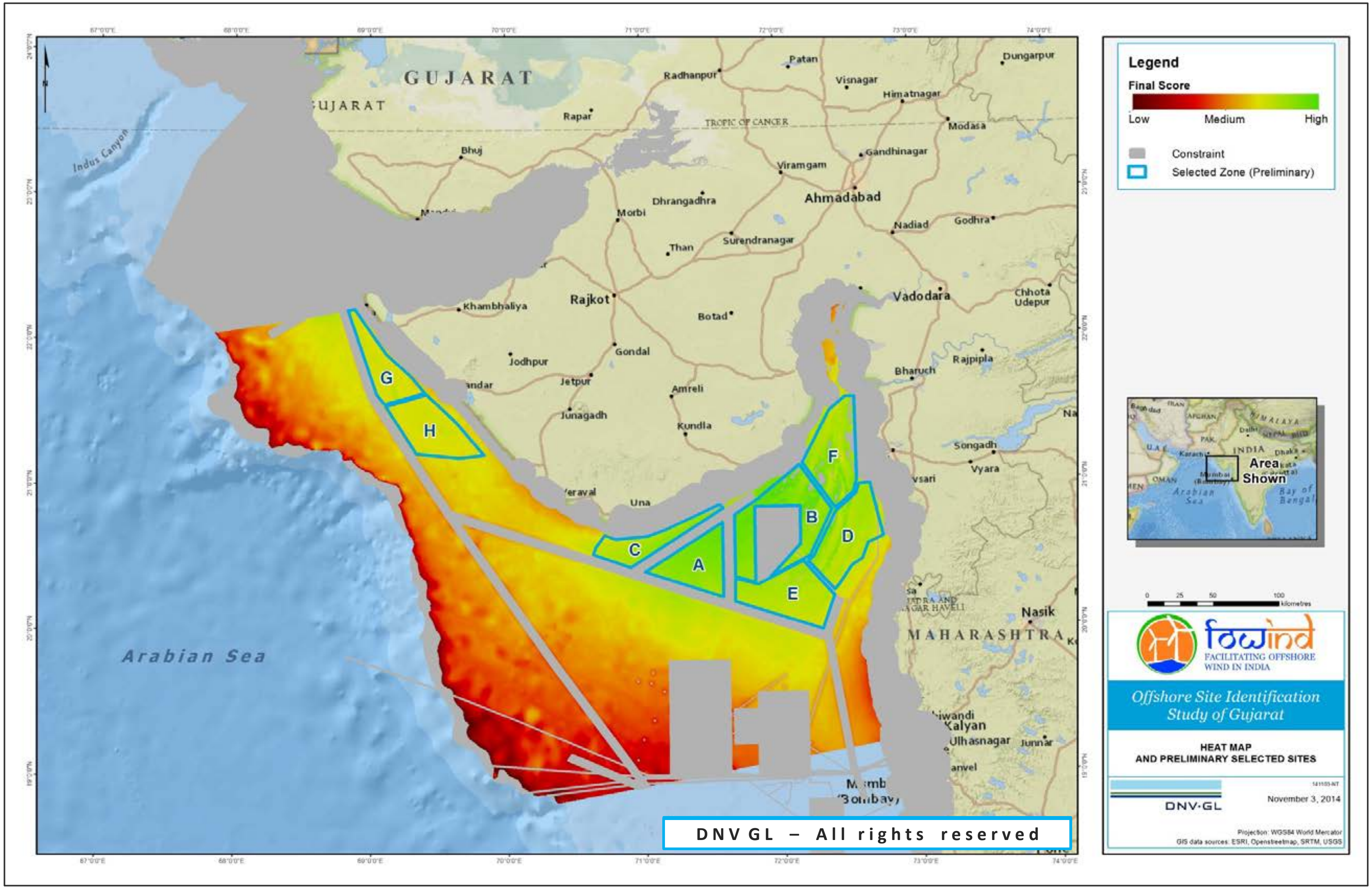


Figure 47: Offshore Heat Map with Potential Development Zones of Gujarat

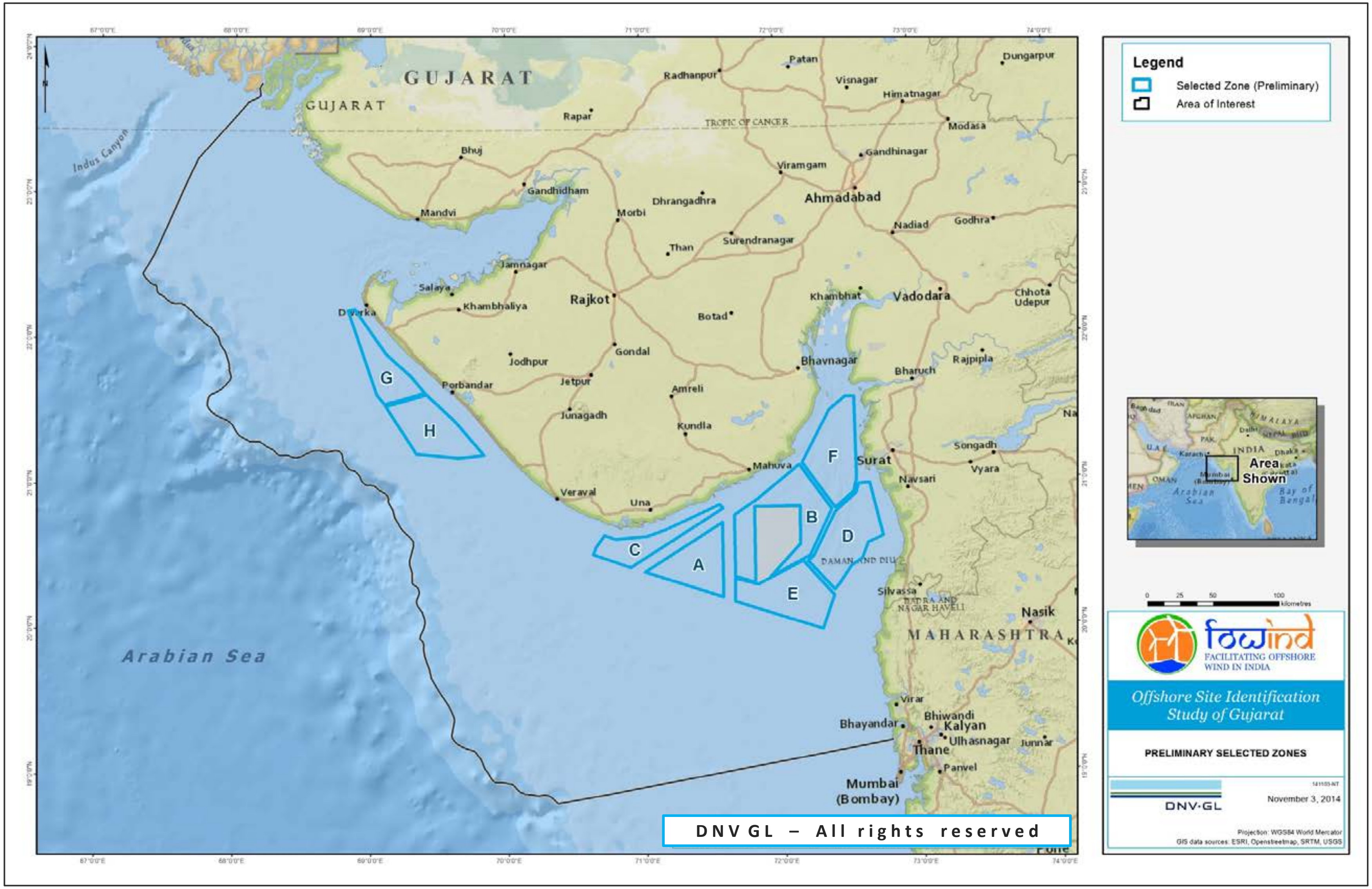


Figure 48: Offshore Potential Development Zones of Gujarat

APPENDIX 4

ENVIRONMENTAL IMPACTS AND POTENTIAL MITIGATION STRATEGIES

Table 53: Impact Analysis on Various Marine Species

Affected species	Impacts	Positive (+ve)/ Negative (-ve)	Mitigation measures	Observations from existing offshore wind projects
Fishes	Introduction of artificial reefs: wind turbine foundations, the boulders used for scour protection and the underground cables function as artificial reefs and locally enhance biomass for a number of species. Moorings or foundations also function as Fish Aggregating Devices for large predatory and pelagic fish[7,8].	+ve	Not applicable	• In Thanet offshore wind farms, certain fish species such as cod, find shelter inside the farm. More porpoises were recorded inside the farm than outside[9]. • In 2012, the effect of Horns Rev 1 offshore wind farm on fish communities were studied and showed an increase in stock of some fish species, post construction[10].
	Noise: the noise associated with the construction of offshore wind-farms (pile driving, boats and ship traffic) could affect marine fish with internal or external injuries, rupturing of swim bladders, damage to eardrum and lead to deafness.	-ve	• Provide bubble curtain during the piling process; • Application of soft-start or ramp-up procedure.	• Pile driving in Horns Reef wind farm affected harbour porpoise acoustic activity on time scales of a few hours[11] • Mortalities were observed after pile-driving in the course of the San Francisco-Oakland Bay Bridge Demonstration Project, USA[12]
	Electromagnetic and heat radiation: magnetic fields generated by cables may impair the	-ve	• Application of suitable cable types to reduce the	• During periods of high power production, cod appeared to avoid the

7 http://cmsdata.iucn.org/downloads/2010_014.pdf
8 http://icesjms.oxfordjournals.org/content/63/5/775.abstract
9 http://www.ewea.org/fileadmin/files/members-area/information-services/offshore/research-notes/120801_Positive_environmental_impacts.pdf
10 http://www.aqua.dtu.dk/english/News/2012/04/120410_Fish-thriving-around-wind-farms
11 http://www.subacoustech.com/wp-content/uploads/544R0308.pdf
12 http://qsr2010.ospar.org/media/assessments/p00385_Wind-farms_assessment_final.pdf

Affected species	Impacts	Positive (+ve)/ Negative (-ve)	Mitigation measures	Observations from existing offshore wind projects
	orientation of fish and marine mammals and affect migratory behaviour. Also, heat dissipation from cables can affect the optimum habitat of certain fishes.		emission of magnetic fields • Shielding of cables to minimise the direct emission of electric fields • Burial of cable to an appropriate depth to reduce the exposure of sensitive species to electromagnetic fields and thermal radiation.	cable route and exhibited a random distribution around the power cables of Nysted offshore wind farm[13].
Birds	• Barrier effect or change in migratory path of the birds • Collision with wind turbine blades • Loss or damage of habitat resulting from turbines and associated infrastructures	-ve	• Avoid the migratory routes of important and sensitive species of birds • Siting turbines clustered together will minimise the development footprint • Grouping turbines to avoid alignment perpendicular to main flight paths within large wind farms • Increasing the visibility of rotor blades to reduce collision risk	• Common eiders were found to avoid flying close to or into the Tuno Knob offshore wind park in Denmark • The proportions of birds approaching Nysted and Horns Rev wind farm area post construction and crossing the wind farm area have decreased relative to the pre-construction baseline. • Birds make gradual and systematic modification to their flight routes in response to the visual stimulus of the wind farm, with more dramatic changes in flight deflection close to the outermost turbines[14].

13http://www.inchcapewind.com/files/Environmental_Statement_Structure/Chapter13/Appendix13C.pdf
14http://www.folkecenter.net/mediafiles/folkecenter/pdf/Final_results_of_bird_studies_at_the_offshore_wind_farms_at_Nysted_and_Horns_Rev_Denmark.pdf

Affected species	Impacts	Positive (+ve)/ Negative (-ve)	Mitigation measures	Observations from existing offshore wind projects
Flora and fauna	Create or enhance natural habitat for organisms living on the seabed.	+ve	Not applicable	• Foundation structure of offshore wind farm Alpha Ventus has been colonised by blue mussels, plumose anemones, and even oysters. • An increase in colony of blue mussels and crabs were observed in the Nysted (DK) offshore wind farm.

APPENDIX 5
MODES AND TRENDS IN OFFSHORE WIND FINANCING

Table 54: Modes and Trends in Offshore Wind Financing.

Source: [57], [104]

Modes of Finance	Prominence in the Sector	How Capital is Accessed	Challenges
Utility Balance sheet financing	Historically, most predominant model of financing in the offshore wind sector; In 2013, 73% of annual installed capacity in Europe was financed by utilities [105] such as DONG Energy, Vattenfall, RWE, SSE and E.ON which are the leading international offshore wind players [106].	Financing can be done by either investing equity in the offshore wind project or by availing debt through the utility's balance sheet. A strong balance sheet is required. Since lending banks do not have to conduct detailed due diligence, cost of financing and timescale is reduced; Alternatively, power producers can establish joint ventures with other producers or use third party capital.	High capital requirements constrain utility's balance sheets.
Project finance[15]	The ongoing financial crisis, tighter lending norms and relative immaturity of the offshore wind market compared to other energy sectors have made many investors much more risk averse; Most commercial banks continue to focus on European countries, where there are several offshore wind projects operating successfully.	This type of project financing typically offers no recourse to the project sponsors' balance sheets. Financing is done on the basis of assessment of future cash flows from the project and requires a higher level of due diligence. Typical debt to equity ratio is 75 :25; Project financing can be done by consortiums of several commercial banks, multilateral institutions and export credit agencies.	Higher risk exposure to lenders; Credit rating agencies perceive non-recourse debt negatively. This can increase the cost of debt as well as risk for the utilities.
Third Party Financing	Third party capital involves non sponsor equity such as infrastructure funds and institutional investors.	Institutional and infrastructure investors are typically looking for large scale and long term investments with a cost of capital in the range 6-13%, provided	Since institutional investors have a low cost of capital, mitigating regulatory risk, i.e. uncertainty in

[15] Most offshore projects that have been project financed in Europe have received support from some government or quasi-government agencies like the European Investment Bank (EIB), Euler Hermes (EH), Green Investment Bank (GIB), EksportKreditFonden (EKF) and KfW. In 2012, the 367 MW Walney project in the United Kingdom received approximately one-fifth of the amount needed for the refinancing of the project from GIB. Experience shows that as the market matures, it requires less help from public finance institutions.

Modes of Finance	Prominence in the Sector	How Capital is Accessed	Challenges
	They are prominent sources of construction and operations financing.	guarantees are available; These investors are more likely to invest if they are assured of long term stability in pricing; Funding can be obtained along with multilateral funding; Third party investors have also started funding the construction phase under project finance deals.	pricing is important; For infrastructure funds, returns on investment comparable to other sectors with similar risk profiles such as oil and other sources of energy are necessary. Therefore, these investors require higher return on investment.
Vendor financing	Vendors such as EPCI contractors and original equipment manufacturers (OEMs) can earn margins through investments in construction, installation and manufacturing	Vendors usually invest a minor stake in equity under project finance; They are useful in winning bid contracts and refinancing debt in existing projects.	Vendor companies typically have restricted balance sheets and lower access to capital, therefore their financing capacity is limited.
Project bonds	Least prominent source of finance, however they may be used in the future mainly for refinancing of offshore wind projects.	Issue of bonds for existing projects to cover operational expenses or for refinancing; Provided by supply chain contractors to show their commitment to the project through shared financial risk. Such vendor financing solutions include providing senior/mezzanine debt, equity investments, and subordination of operational costs, transferring capital expenditure (CapEx) to operational expenses and guaranteeing pre-completion revenues.	This mode of financing can generally be used for existing projects; They have not played a prominent role so far in offshore wind project financing and are unlikely to do so in the future.

Table 55: Sources for Debt Financing for Offshore Wind Projects

Sources of debt	Features
Commercial Banks	• Most prominent source of lending for offshore wind projects • Carry out extensive due diligence which is time consuming • Usually lend on some multilateral involvement or guarantee • Financial crisis and introduction of Basel III norms[16] have reduced their risk appetite • Examples are Deutsche Bank, BNP Paribas, HSH Nordbank, Bank of Ireland etc.
Multilateral Institutions and development banks	• Typically have investment mandates • Offshore wind project goals align with multilateral institution goals of green energy, economic growth and jobs • RE technologies need capital support in their initial years to become viable • Examples are World Bank, ICF, KfW Germany, EIB
Export Credit Agencies	• Provide loans/grants to promote exports to encourage domestic income growth • They can also provide guarantees and senior capital to other lenders at cheaper rates • They have played a major role in financing several offshore wind projects. Examples of projects are Butendiek Germany, Thornton Bank and Blight Bank Belgium

Table 56: Types of Equity Investors in Offshore Wind Financing

Source: **[57]**

Type of Investor	Drivers of Investment	Examples of Industry Players
Power Producers	• Development, construction and operation of project; • Improving cost effectiveness in construction and operation; • Lower cost of capital and lower time required to access capital; • Greater control over the project.	Dong Energy, Vattenfall, E.ON, RWE AG, SSE plc, Centrica plc, Statkraft, Eneco, EnBW AG.
EPCI Contractors	• Margins on installation, manufacture and maintenance; • More investment in offshore wind means more business.	Siemens, BARD Engineering GmbH.
Oil and gas companies	• Synergies in offshore construction and operation; • Experience in large onshore as well as offshore investments.	Statoil, Statkraft.
Independent developers	• Important stakeholders in the project, can leverage their experience in the sector to attract equity from investors.	Mainstream Renewable Power, Warwick Energy and SeaEnergy.
Institutional investors	• Investments that will generate long term, low risk yields and large scale investment.	Pension Danmark, PGGM Netherlands.
Infrastructure funds	• Significant returns in comparison to investments with similar risk profiles. • Arbitrage from selling projects at lower rates of return after some period of investment.	Marguerite Infrastructure Fund, Copenhagen Infrastructure Partners.
Corporate investors	• Energy intensive corporate may benefit by securing energy supply; • Long term stable returns; • Positive impact on brand and PR.	Colruyt (Belgian Retail Corporation), Sumitomo Corporation Japan.
Sovereign Wealth Funds	• Government's objectives of promoting renewable energy.	Masdar (Abu Dhabi State Renewables Developer).

PROJECT PARTNERS

Global Wind Energy Council (Brussels, Belgium) is the international trade association for the wind power industry. The members of GWEC represent over 1,500 companies, organisations and institutions in more than 70 countries. *www.gwec.net*

Center for Study of Science, Technology and Policy (Bangalore, India) is one of the largest think tanks in South Asia; its vision is to enrich the nation with technology-enabled policy options for equitable growth. *www.cstep.in*

DNV GL is the world's largest provider of independent renewable energy advice. The recognized authority in onshore wind energy, DNV GL is also at the forefront of the offshore wind, wave, tidal and solar sectors. *www.dnvgl.com*

Gujarat Power Corporation Limited (Gandhinagar, India) has been playing the role of developer and catalyzer in the energy sector in the state of Gujarat. GPCL is increasing its involvement in power projects in the renewable sector, as the State of Gujarat is concerned about the issues of pollution and global warming. *www.gpclindia.com*

World Institute of Sustainable Energy (Pune, India) is a not-for-profit institute committed to the cause of promoting sustainable energy and sustainable development, with specific emphasis on issues related to renewable energy, energy security, and climate change. *www.wisein.org*

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FACILITATING OFFSHORE WIND IN INDIA

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