



Marine Spatial Planning for Offshore Wind Development in Gujarat

Revision 2

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Disclaimer

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The DEA would like to acknowledge all the stakeholders in India, as well as the various sources for data and information used. Without these contributions, it would not be possible to produce this report.

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Executive summary

This report investigates the potential for offshore wind development off the coast of Gujarat, north west India. Through gathering information on the physical characteristics – including wind speeds and water depths – the most favourable sites are identified, before examining potential conflicts with other use cases of the sea area, development restrictions and social and environmental impacts. The collection of such information, from a wide range of stakeholders, forms the basis of a Marine Spatial Plan (MSP). This is a tool used by policy makers and planners to accommodate the broad range of interests at sea.

This revision builds on the first MSP for Gujarat (Centre of Excellence for Offshore Wind and Renewable Energy, 2023) published in February 2023 by The Centre of Excellence for Offshore Wind and Renewable Energy. It includes new updated data and information, and focuses on the identification development sites which could be tendered in a pipeline of projects in the region.

The identified sites with favourable conditions for offshore wind development could accommodate a total of 11.8 GW of bottom-fixed turbines, based on a density assumption of 5 MW per km². This is in addition to the 0.5 GW site already tendered with Viability Gap Funding. This study showcases the significant potential for Gujarat to harness the power of offshore wind in developing a robust, diverse and sustainable energy system. The high complexity of the stakeholder interests raised in this report emphasises the need for a clear direction from government to prioritise space at sea and ensure that the limited suitable areas are used wisely.

The following recommendations for the further development of offshore wind off the coast of Gujarat are based on MSP principles and are detailed further in Section 7: Recommendations.

1. Focus on offshore rather than nearshore wind development

It is recommended to prioritise offshore wind development beyond the 12 nautical mile boundary, targeting zones with high potential capacity of approximately 11.8 GW due to significant nearshore constraints.

2. Allocate space at sea for offshore wind legally through a political agreement

Sea space in favourable offshore zones should be legally reserved via political agreements to balance wind energy development with existing oil, gas, and other economic activities.

3. Prioritise efforts, starting with the best sites

Development should begin with the most cost-effective zones to accelerate initial offshore wind projects and support supply chain maturation.

4. Stakeholder engagement

Early and coordinated stakeholder engagement through Marine Spatial Planning is essential to ensure consensus, mitigate risks, and facilitate timely project progress.

5. Site investigations

Preliminary site investigations, including seabed and environmental surveys, are critical to reduce risks and inform appropriate project design and mitigation.

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Abbreviations

[AAI]	Airports Authority of India
[ARP]	Aerodrome Reference Point
[CRZ]	Coastal Regulation Zone
[CSTEP]	Centre for Study of Science, Technology and Policy
[CZMP]	Coastal Zone Management Plan
[DSF]	Special Discovered Small Fields
[EIA]	Environmental Impact Assessment
[FOWIND]	Facilitating Offshore Wind in India
[GOGI]	Global Oil and Gas Infrastructure
[GPCL]	Gujarat Power Corporation Limited
[GSHAP]	Global Seismic Hazard Assessment Program
[GSI]	Geological Survey of India
[GWEC]	Global Wind Energy Council
[IFR]	Instrument Flight Rules
[IMMA]	North East Arabian Sea Important Marine Mammal Area
[LNG]	Liquefied Natural Gas
[MNRE]	Ministry of New and Renewable Energy
[NIWE]	National Institute for Wind Energy
[OALP]	Open Acreage Licensing Policy
[R2]	Correlation Coefficient of Determination
[SEA]	Strategic Environmental Assessment
[VASAB]	Vision and Strategies Around the Baltic Sea
[VFR]	Visual Flight Rules
[VGF]	Viability Gap Funding
[WISE]	World Institute of Sustainable Energy

1. Introduction

India and Denmark have been cooperating on developing relevant policies, strategies, and solutions to enable a low carbon transition of the Indian energy sector since 2018. The government-to-government collaboration aims at making relevant Danish experience available for inspiration in India's green transition. The overall objective is to support Ministry of New and Renewable Energy (MNRE) in their work for the implementation of 37 GW offshore wind by 2030.

The main objective of this assignment is to identify the most suitable zones for deployment of offshore wind in India in the states of Tamil Nadu and Gujarat in accordance with the renewable policy and target of 37 GW offshore wind by 2030. The most suitable zones and project sites for deployment of offshore wind will be identified via maritime spatial planning by examining the different interests of marine space usage and the conditions required for offshore wind. This report focuses on Gujarat and presents the importance of marine spatial planning in space negotiation and cross-sectoral cooperation.

Since the first revision of this report on MSP in Gujarat, published in February 2023, the Government of India has announced the Strategy Paper for the Establishment of Offshore Wind Energy Projects, rev. 02 of 26 September 2023, which outlines a pipeline of sites for development including one area in Gujarat, zone B3, which has been designated for a 500 MW site eligible for Viability Gap Funding (VGF) under Model A. In this report the zone B3, is marked as the hashed area in most maps to give an indication of size and location of the other potential zones. The Strategy Paper outlines a pipeline of another 500 MW VGF site in Tamil Nadu and a further 14 GW of offshore wind sites in Tamil Nadu under the tender scheme (Model B). This brings the total pipeline for tendered sites up to 15 GW. In order to reach the targeted 37 GW, a third scheme (Model C) allows developers to identify sites around the coastline and propose projects (Ministry of New and Renewable Energy, 2023). This study aims to examine the coastline of Gujarat for further sites which can be included under the tender scheme (Model B) in a revision.

This report will build upon the first revision by describing the screening methodology and presenting the most suitable zones off the coast of Gujarat for further stakeholder consultations and inputs. The first revision of the MSP report for Gujarat was based on zones identified in the FOWIND project, published in 2015. This report examines revises the definition of these original zones, according to the latest information and data on the usage of the sea space. It also includes consideration for development zones both offshore and nearshore, delimited by the 12 nautical mile coastal boundary (GWEC et al., 2018).

Updates from the MSP report revision 1 from 2023 to this revision 2, includes new and updated information on e.g. marine traffic, shipping routes volume and patterns, environmental factors regarding marine and bird life, fishery, raw material extractions and interfaces to the oil and gas exploration fields in the area.

1.1. Objectives and scope

The objectives of this project are:

1. To describe the methodologies used for assessing and ranking potential offshore wind sites, in order to provide best practise to the NIWE and other Indian stakeholders on Marine Spatial Planning and screening.
2. To improve the decision basis for selection of suitable sites for offshore wind development through screening, planning and ranking of preselected sites.
3. To assess offshore wind sites, and establish the importance of Marine Spatial Planning in building up a pipeline of offshore wind projects.
4. Identify a pipeline of offshore wind projects within the identified wind zones of Gujarat to support the overall target of 37 GW by 2030.

2. Methodology

This report screens potential offshore wind development zones in Gujarat. It starts by looking at the fundamental physical parameters for a successful project; wind speed and water depth (when looking at bottom-fixed foundations). Suitable areas are then further examined to identify factors which could exclude them from development, for example highly sensitive ecosystems or certain types of commercial activity. This detailed screening results in a list of suitable sites for offshore wind development, which are then ranked according to their financial favourability. This is estimated by using the physical characteristics which influence the Levelized Cost of Energy, a value which can be used to compare electricity costs from different generation sources.

The intention of the study is to identify sites where authorities should focus their attention when investigating the development of offshore wind, and to raise some potential barriers to development due to stakeholder interests, environmental sensitivity and other uses cases of the sea area. These resultant sites must then be examined in closer detail through preliminary site surveys and environmental impact assessments.

3. Cost Map

Two key factors behind a robust business case for offshore wind include wind speed and water depth. These variables have a significant influence on the cost of electricity generated, and can be used to create a rough screening of India's marine territory to highlight areas of interest for more detailed screening.

Figure 1 shows the mean annual wind speeds at 150 m elevation in the offshore region of Gujarat taken from the Global Wind Atlas. It shows that the highest windspeeds (coloured dark green) are close to the shore off the southern coast of the Saurashtra peninsular.

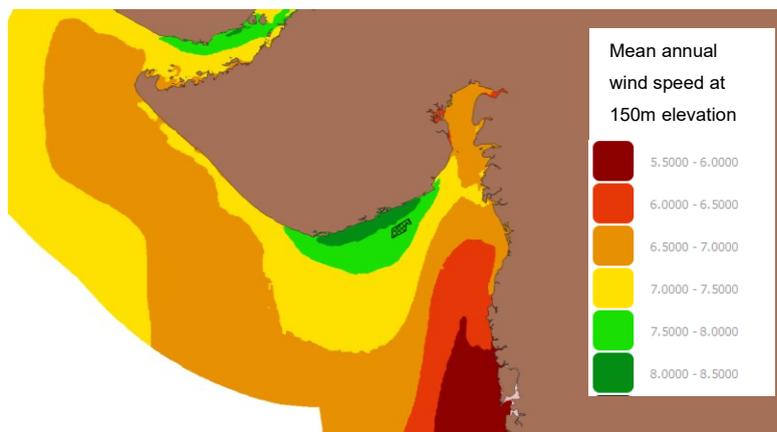


Figure 1 - Map showing mean annual wind speeds (m/s) at 150 m elevation, taken from the Global Wind Atlas. Hashed area is zone B3.

Figure 2 shows the bathymetry, or water depth, in the Gujarat offshore region. Although bottom-fixed offshore wind turbine foundations are generally suitable for water depths between 10 to 65 meters, considering previous MSP results and lessons learned (GWEC et al., 2018), this work use 50 m as the lower boundary. In this way, areas with a water depth of below 50m are coloured dark blue and indicate areas where bottom-fixed foundations are not feasible, or would be prohibitively expensive. Bathymetry is very dynamic and changes rapidly in the Gulf of Khambhat. Superficial clay layer with weak shear strength, followed by sand layers at various depths, which are relatively denser (GWEC et al., 2018).

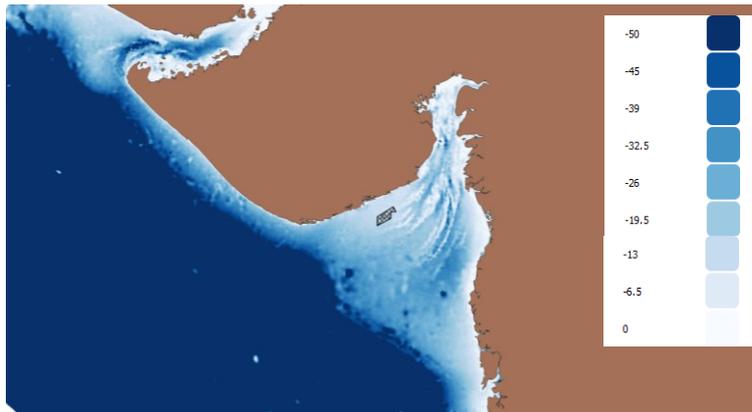


Figure 2 - Water depth (m) taken from the global wind atlas, hashed area is zone B3.

By combining these two key parameters, an indicative heat map has been created as shown in Figure 3. Green areas are suitable for bottom-fixed foundation offshore wind farms as they meet the criteria for water depth (>10m and <50m) and average annual wind speed (>7m/s). The darker the green, the higher the wind speeds and the shallower the water depth is. This indicated areas which would most likely have the lowest Levelized cost of Energy for installing offshore wind. Note that areas with a water depth shallower than 10m have been excluded as these present an access challenge to typical installation vessels, and also represent areas with dynamic sand layers. Details on the heat mapping method is given in Appendix B.

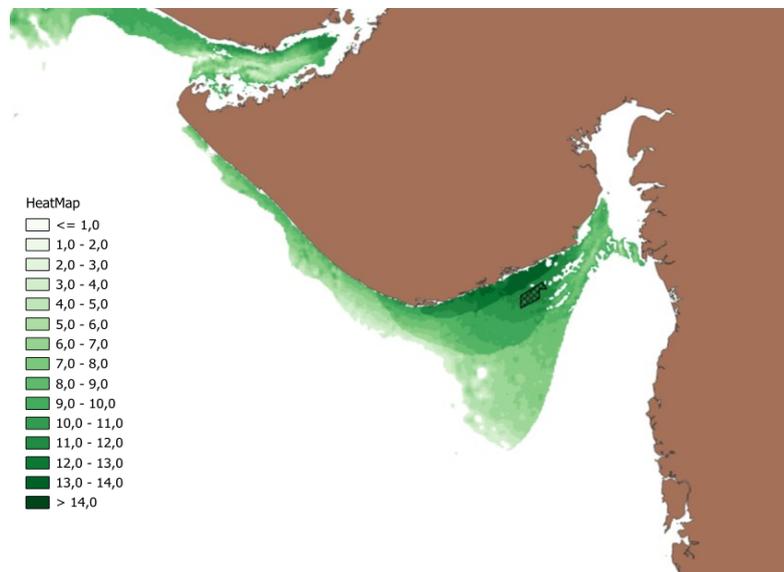


Figure 3 – Indicative weighted heatmap showing areas with the best wind speed and water depth conditions for offshore wind development with the darkest green shading.

4. Restrictions and limitations for offshore wind development

When screening for suitable sites for offshore wind, a number of restrictions and limitations might have significant influence on the suitability of selected areas and need to be assessed thoroughly. These factors, either individually or in combination, may become showstoppers for the further development of the project. This report is focusing on the most common restrictions and limitations to be considered during initial screening processes, such as:

- Coastal zone management
- Commercial traffic, e.g. air and sea
- Environment and ecosystems
- Economical interest of stakeholders
- Infrastructure, e.g. cables, pipelines
- Military
- Culture and heritage
- Seismic

4.1. Coastal Zone Management

Development on the coastline of India is regulated through the Coast Regulation Zone (CRZ) Notification 2011, which builds on earlier revisions of the same notification. It divides the coastal area into four zones spanning the onshore coastal region up to the 12 nautical mile offshore boundary, illustrated in the conceptual diagram in Figure 4.

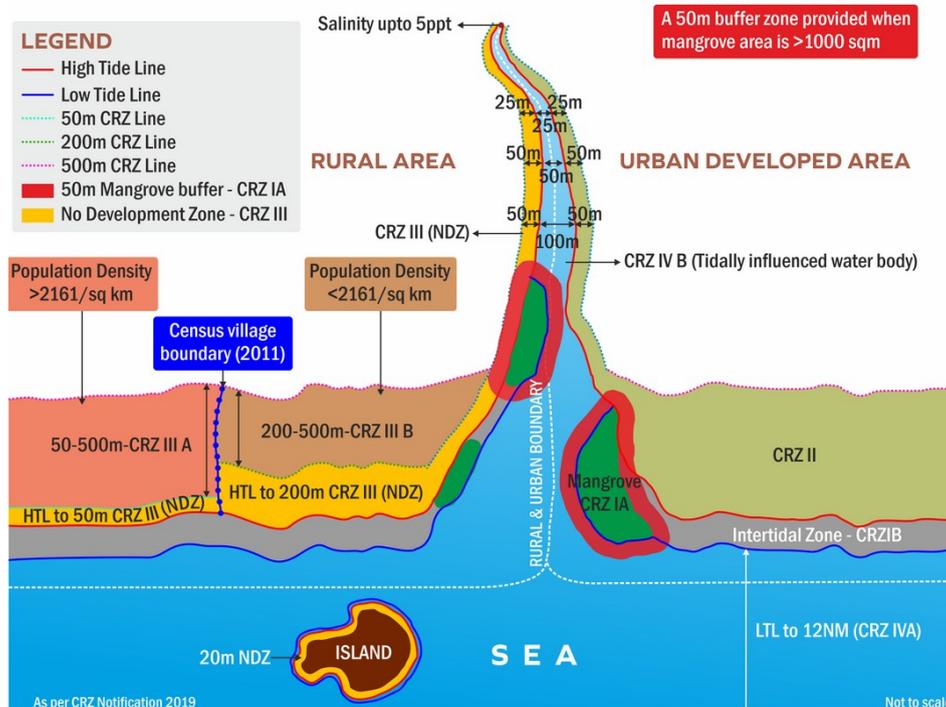


Figure 4 - Conceptual diagram of coastal zone management plan.

CRZ I: Ecologically sensitive areas

a) The areas that are most ecologically sensitive where the geomorphological features play a role in maintaining the integrity of the coast. This includes mangroves, coral reefs, sand dunes, mudflats and protected areas.

b) Intertidal Zone: The area between low tide line and high tide line

CRZ II: Developed areas: Areas that have been developed up to the high tide line, for example urban areas and infrastructural facilities.

CRZ-III: Relatively Undisturbed Areas: Typically, within rural areas with low levels of development which belong to neither CRZ I or II.

CRZ-IV: Sea Areas: The area from the low tide line to 12 nautical miles offshore.

These zones have varying restrictions for development which are outlined in the notification. Generally projects for generating power by non-conventional energy sources are permitted but must submit a description of project activities within the affect CRZ boundaries and obtain clearance. An offshore wind farm including the power evacuation infrastructure and onshore grid connection will include CRZ IV, and depending on where the landfall is made, one of the other three zones. For any nearshore wind farm development (less than 12 nautical miles offshore), the entire project would fall within the CRZ regulation area. Maps of the Indian coastline is available at <https://czmp.ncscm.res.in/#main-map> showing the categorization of the various coastal areas (National Centre for Sustainable Coastal Management, n.d.).

4.2. Marine traffic

The state of Gujarat has 48 minor ports and one major port. The proposed offshore wind development zones are located close to several large ports, and therefore consideration of traffic density and navigations routes is essential.

The original offshore wind development zones were drawn in 2015 as part of the Pre-feasibility for Offshore Wind Farm Development in Gujarat study by FOWIND (GWEC et al., 2015). The map of these zones is shown with the density of marine traffic in Figure 5.

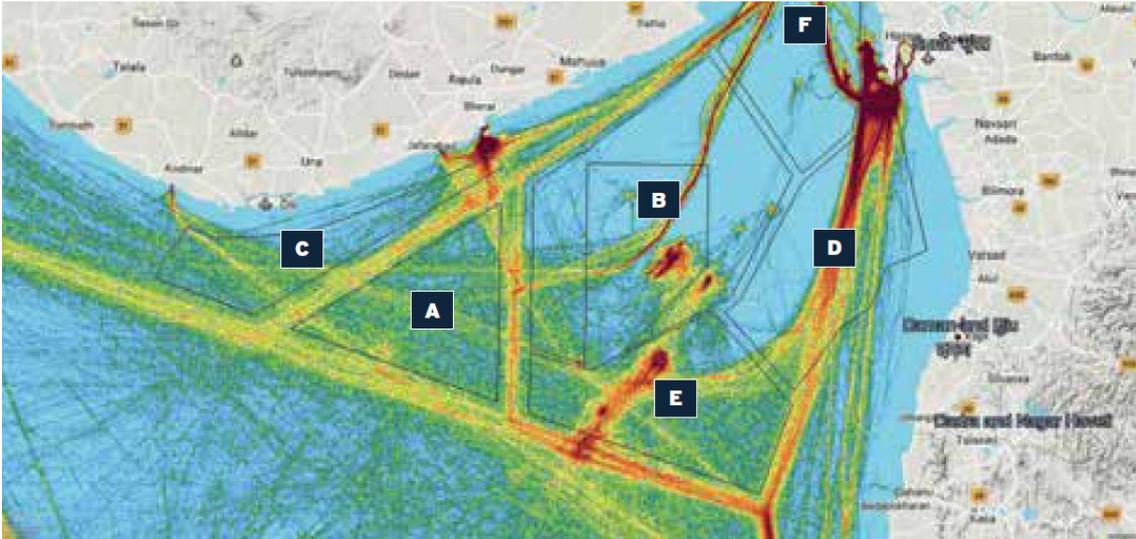


Figure 5 - Marine traffic density and the offshore wind development zones in the Feasibility for Offshore Wind Farm Development in Gujarat study by FOWIND.

AIS data for 2022 and 2023 shows that the distribution of marine traffic in the Gulf of Khambhat has changed somewhat since 2015 when the development zones were first drawn as shown in the FOWIND Report (GWEC et al., 2018).

Given that the original zones were drawn based on the marine traffic data from before 2015, and there is evidence that the traffic patterns have changed, it is proposed to adjust the zone boundaries to accommodate marine traffic to reduce conflict, and to define shipping routes ensure that traffic patterns remain consistent. The zones have been redrawn to accommodate the marine traffic patterns from recent years up to 2023, as shown in the FOWIND Report (GWEC et al., 2018), and also to reflect the higher wind resource closer to the coastline at Jafrabad, see Figure 6. In the interest of identifying zones suitable for several wind farms, this study also includes nearshore areas, within the 12 nautical mile coastal boundary. The coordinates of the proposed zones are given in Appendix A.

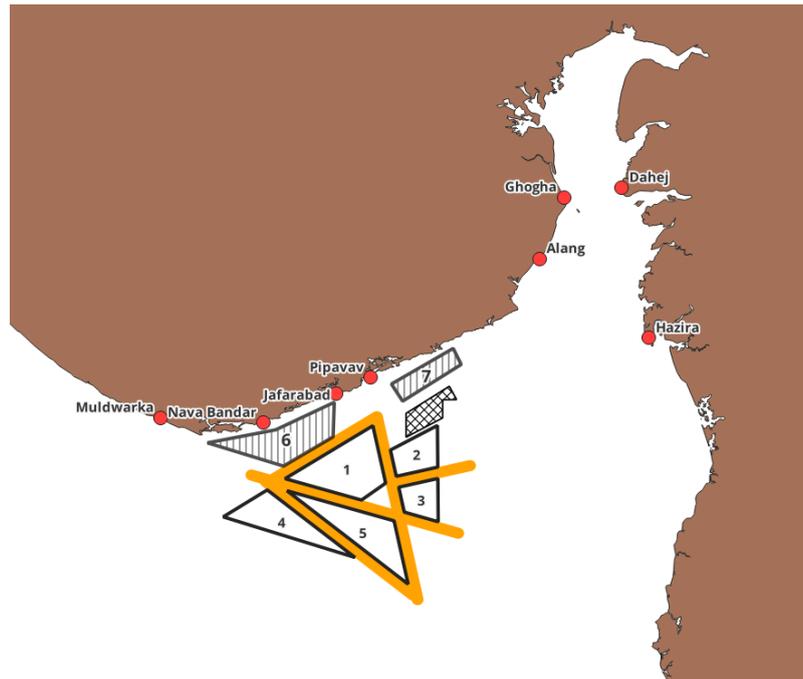


Figure 6 - Proposed development zones (numbers 1 to 7) accommodating key marine traffic corridors (orange) with a width of 5km. Shaded areas (6 and 7) are nearshore zones. The hashed region is the 500 MW site with allocated Viability Gap Funding.

The most westerly port shown on the map is a cement production facility at Muldwarka where cement carrying vessels transport product to other ports. Closest to the OSW development zones are the ports of Jafarabad and Pipavav. Further north, into the Gulf, are the ports of Ghogha and Dahej, which is a terminus of a Liquefied Natural Gas (LNG) pipeline. Many of vessels arriving at Dahej are carrying LNG. Alang is the world’s largest ship breaking yard, where more than one third of the world’s retired cargo ships are salvaged. On the eastern coast of the Gulf is Hazira Port, which is a large multi-cargo deep water port, and an LNG terminal.

There is a high density of marine traffic in a clearly defined channel to the south of the OSW development zone. The route into the mouth of the Gulf towards Dahej port is confined into a channel width of less than 2 km which is likely dredged due to the shallow water and dynamic bathymetry. The channels between the proposed OSW development sites are 5 km wide, to accommodate both the traffic levels and a safety margin. According to IMO guidelines for marine traffic lanes (Baltic LINes Project, 2018), a two-way shipping lane of width 1.6 km per lane, plus a 500 m buffer zone between and on either side, giving a total width of 4.7 km is able to accommodate up to 4400 vessels per year in each direction, therefore providing capacity for a potential increase in traffic in future and to ensure adequate safety margin for vessels, in particular those carrying LNG which present an environmental risk. Nonetheless, it is suggested that site-specific analyses, supported by navigational risk models, are carried out for providing a deeper

insight into the required shipping lanes width, to ensure the adequate safety margins for vessels and maximize the available offshore wind development area.

The rest of this study will focus on assessing the suitability of these proposed zones for offshore wind development and identifying potential environmental, social and industrial conflicts.

4.3. Environment

4.3.1. Ecosystems

Gujarat is the only state on the west coast of India with coral reefs. The other ecosystems present in the coastline are the seagrass, seaweeds, mangroves, beaches, and coastal dunes. The majority of these sensitive ecosystems are located within the Gulf of Kutch, and therefore this region has been excluded from the site selection for offshore wind development. The region of interest, on the south coast of the Saurashtra peninsula in the Gulf of Khambhat, also has some sensitive ecosystems, include an area of mangrove cover (Gujarat Infrastructure Development Board, n.d.). These areas are designated as ecologically sensitive under Coastal Regulation Zone I.

An example from the Coastal Zone Maps is given in Figure 7 which shows the coastal area around Mahuva, the closest point to the proposed offshore wind development zones, in particular the VGF zone B3. This coastline includes highly sensitive ecosystems in the intertidal zone, including mangroves. This area is the proposed landing point from the preliminary study for the export cable for the VGF offshore wind project at zone B3, from which an underground cable segment will lead up to the Mahuva onshore pooling station (DeshGujarat, 2025), (PowerGrid, 2025). The exact location of which will depend on several factors, including ground conditions, access and environmental considerations.



Figure 7 - Coastal Zone map, Sheet no. GJ32, Grid No. F42X9/NE. Green areas are Mangroves protected under category CRZ – IA and surrounded by a 50 m buffer zone. The orange areas are 'No Development Zones' under CRZ III.

4.3.2. Marine life

Although the coastline of the southern Saurashtra peninsula is not as rich in marine life as the Gulf of Kutch, it still hosts a significant diversity of species and habitats.

All the five species of sea turtles found in India, are protected under India's Wildlife Protection Act, 1972. Their population is also considered 'vulnerable' under IUCN's Red List. Four species of sea turtles—olive ridley turtles, green turtles, leatherback turtles and hawksbill turtles are found in the waters off Gujarat, but only the first two are known to nest along the western coast of the Saurashtra peninsula from June to January, which does not present a direct conflict with the proposed offshore wind zones to the south (Sunderraj et al., 2006). Indicative maps showing the distribution of nesting sites in shown in Figure 8.

Movements and behaviours of all these species throughout the region and the seasons is important to understand in order to assess the potential impact of the development of offshore wind. In addition, the potential impact of offshore wind development on other species which may form part of the turtles' prey and wider ecosystem, must be considered (Dakshin Foundation, n.d.).

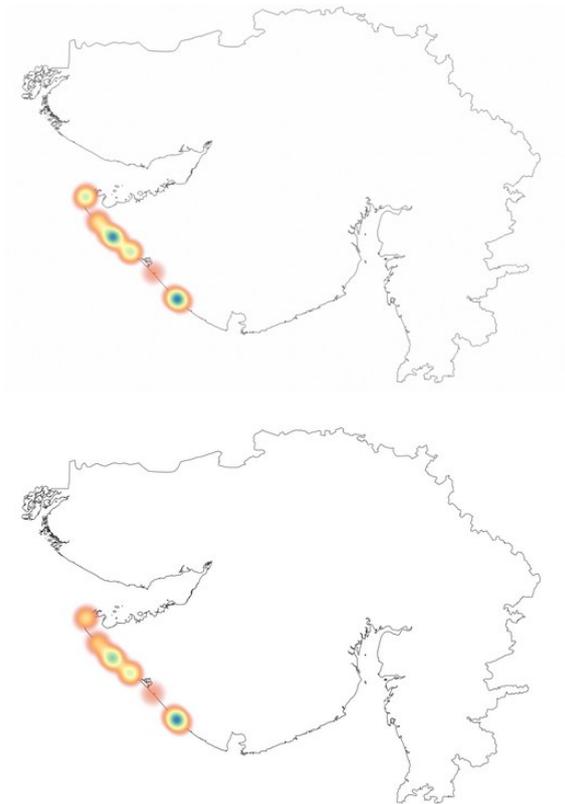


Figure 8 - Distribution of nesting sites for the Olive Ridley (upper) and Green (lower) turtles in Gujarat (Dakshin Foundation, n.d.).

The North East Arabian Sea Important Marine Mammal Area (IMMA), shown in Figure 9, includes the coastal and offshore waters from Ormara (Pakistan) to Kutch-Saurashtra (India). This area is

known for the diversity of marine mammals, including Arabian Sea humpback whales (*Megaptera novaeangliae*), blue whales (*Balaenoptera musculus*) and Bryde's whales (*Balaenoptera edeni*). Arabian Sea humpback whales form a small, isolated subpopulation that is genetically distinct from other populations of humpback whales and remains in the Arabian Sea year-round. This population is designated as Endangered on the IUCN Red List of threatened species. Systematically reported observations by fishermen in Pakistan and India indicate that the area is still used by humpback whales today. In addition, large schools of spinner dolphins (*Stenella longirostris*) and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) are frequently observed in the area.

The marked IMMA does not directly overlap with the proposed offshore wind development zones, however further investigation into the movement and seasonal behaviour of these species is required to assess the potential impact of offshore wind development.

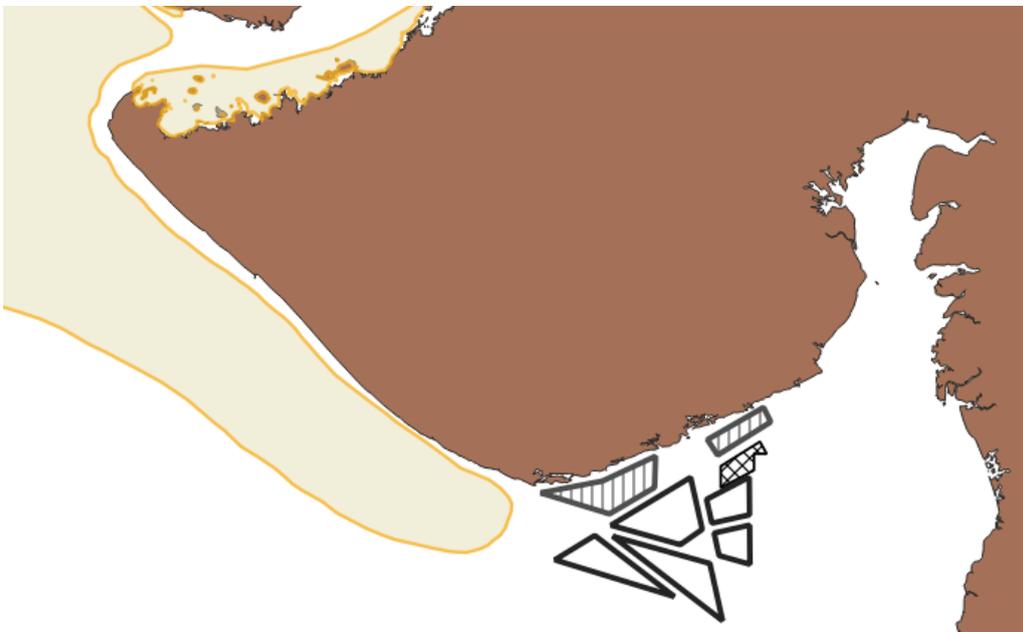


Figure 9 - The North East Arabian Sea Important Marine Mammal Area (IMMA) shown in yellow, with the location of the proposed offshore wind development zones marked.

The presence and construction of wind turbines can affect marine life activity-level. The most influential factor is underwater noise during construction, where especially unmitigated pile-driving of monopile foundations generates high sound pressure-levels across a vast area. High sound-levels can lead to permanent and temporary hearing loss in marine mammals (Madsen et al, 2006) and turtles (CMS), and enhance energy consumption during movement. Furthermore, increasing turbidity and noise from vessel activity can temporarily decrease local populations of marine mammals and fish.

To limit such effects, a variety of mitigating actions can be implemented. A combination of noise reducing measures are frequently used, for instance, reducing sound-levels from pile-driving by

usage of bubble curtains, hydro sound damper, jetting, soft-starting etc., usage of different foundation types that are less noise polluting, such as gravity-based, suction-bucket etc., construction in certain seasonal periods and acoustic deterrents to displace species before commencing construction activities (Tougaard et al, 2012).

Foundations and their scour protection can form artificial reefs and increase the population of fish fauna due to build up of marine growth communities that attracts reef fish and consequently marine predators (DEA, 2006). The presence of wind farms may also limit the amount and/or type of fishing activity, which has the potential to increase fish populations and attract non-indigenous species to the local ecosystem depending on the present substratum (Mesel et al, 2015).

The necessity for mitigating measures depends on the activity level within the offshore wind development area and the specific project, e.g. the sound-level sensitivity for marine mammals varies between low- and high-frequency hearing groups. Therefore, continuous surveys of the marine environment are highly recommended to determine the required mitigating actions, so it is possible to construct offshore wind farms in areas nearby habitats, particularly in regards to underwater noise pollution. In-depth knowledge of local ecosystems would allow for more precise planning in regards to determine foundation type and reducing underwater sound levels.

4.3.3. Birdlife

The Nikol-Samadhiyala-Malan Wetlands Complex is a key biodiversity area located on the coastline close to zone 7 and the VGF site for offshore wind development, see Figure 10. It is home to several bird species which have varying red list statuses including three critically endangered species listed in table 1, as well as a large population of waterfowl.

Kaj Lake is situated in Junagadh district lies close the nearshore development zone 6. It is a tidal regulatory dam where tidal water from the Arabian Sea touches the dam during high tide. One side of the dam is a large, shallow freshwater lake with moderate vegetation and on the other side the tidal mudflat attracts thousands of waterfowl in winter. The maximum water depth is seen during July and August and minimum during March when the lake is totally dry. It is also home to vulnerable and threatened avian species, see table 2.

Further information about these Key Biodiversity Areas, and their protected status, can be found at <https://datazone.birdlife.org/country/factsheet/india>. It should also be noted that this coastline represents an important habitat for birdlife, both inside and outside of the designated protection areas. A thorough assessment of the species present in the area, including their behaviour and migration patterns is required in order to understand how they may be affected by the development of offshore wind – through disruption of their flight paths and breeding and feeding grounds.

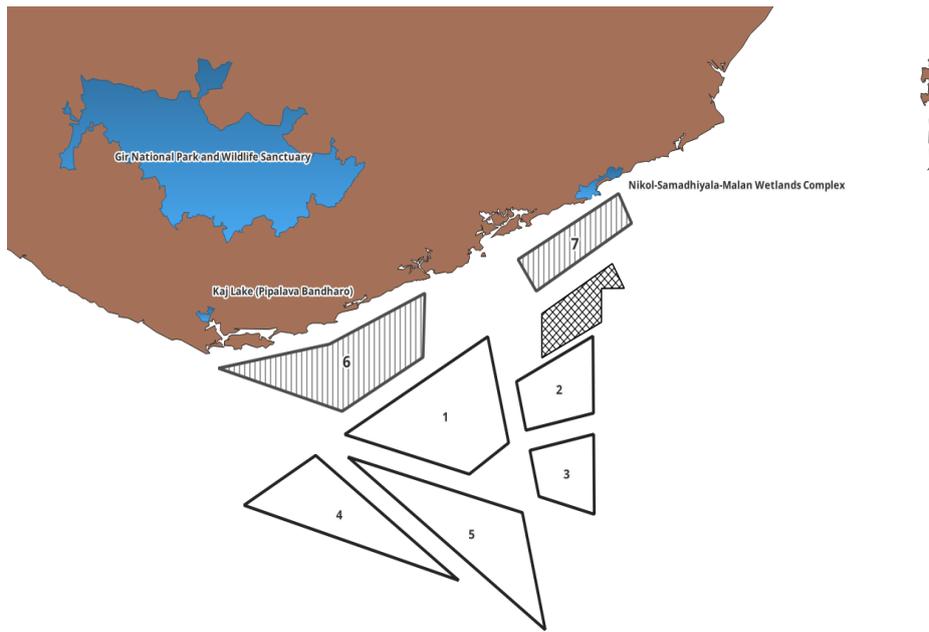


Figure 10 - (BirdLife International, 2025).

In regards to offshore wind farms, water birds can forage and rest in or nearby a wind farm area, while migratory birds can be affected in their seasonal flights. Figure 11 describes the typical impacts from offshore wind farms on birds. This includes displacement from or changes to key habitats, creation of barriers that increase energy consumption or collision with turbine blades. The potential impact of wind farms depends on the overlap with habitats and the species present in the local ecosystem. For instance, populations of larger species with longer lifespans and lower reproduction rates can be more sensitive to increased mortality (Fox, 2019). In other cases, the impact can be non-existent due to limited presence and/or high adaptability/reproduction rates (WSP, 2024), (DEA, 2006).

Considering current migration routes in the planning stages of offshore wind farms enables mitigation of negative impacts on populations. Mitigation measures can avoid substantial population fatalities (Gartman et al, 2016) e.g. curtailment of power output during migration periods, early site selection, enhanced monitoring, specifying construction periods, use of larger but fewer turbines, painting of blades or specific layout configurations.

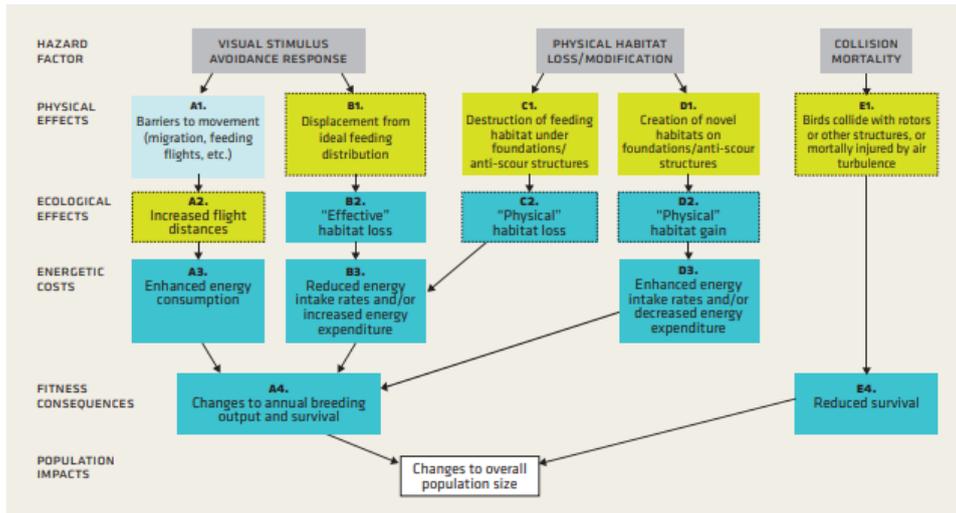


Figure 11 Hazard factors to birds from Offshore Wind Farms (Danish Energy Agency, Danish Offshore Wind - Key Environmental issues p. 95)

The effectiveness and energy output varies across the different mitigating actions. Avoiding high-risk areas through early site selection is effective and often lowers the necessity of further actions that can be more costly and potentially less efficient due to difficult implementation such as curtailment of power production (Gartman et al, 2016). In areas with large consistent migration patterns, curtailment could be considered supplemented with increased monitoring. Other considerations such as contrasting the blades is suggested to lower collision risk for specific species and increase the amount of potential wind farm sites due to decreased mortality rates (Roel et al, 2020). Such considerations are key to introduce for developing offshore wind farms in areas of high biodiversity. Furthermore, if there is a lack of previous experience with effects of offshore wind farms to certain species, it is possible to introduce monitoring through Before After Control Impact (BACI) and introduce mitigation afterwards. Some effects e.g. during construction will only be possible to implement in later projects.

The specific mitigation mechanism depends upon habitat, species and wind farm area. Therefore, it is recommended to survey different species to avoid under- or over implementation of mitigating measures at later project stages. In this way, knowing habitats and relevant mitigation actions will ensure a more efficient project execution from an environmental protection and economic perspectives.

Scientific Name	Common Name	Red List category	Season	Population estimate
Platalea leucorodia	Eurasian Spoonbill	Least Concern	Non-breeding	1500
Limosa limosa	Black-tailed Godwit	Near Threatened	Winter	5000
Gyps indicus	Indian Vulture	Critically Endangered	Non-breeding	present
Sterna acuticauda	Black-bellied Tern	Endangered	Resident	present
Sarcogyps calvus	Red-headed Vulture	Critically Endangered	Non-breeding	present
Gyps bengalensis	White-rumped Vulture	Critically Endangered	Non-breeding	present

Table 1 - Bird populations meeting Key Biodiversity Area criteria present in Nikol-Samadhivala-Malan Wetlands Complex.

Scientific Name	Common Name	Red List Category	Season	Population estimate
Platalea leucorodia	Eurasian Spoonbill	Least Concern	Winter	500
Limosa limosa	Black-tailed Godwit	Near Threatened	Winter	7000
Aquila heliaca	Eastern Imperial Eagle	Vulnerable	Winter	present
Calidris pugnax	Ruff	Least Concern	Winter	1000
Anthropoides virgo	Demoiselle Crane	Least Concern	Winter	27120
Clanga clanga	Greater Spotted Eagle	Vulnerable	Winter	present
Pelecanus onocrotalus	Great White Pelican	Least Concern	Winter	300
Pelecanus crispus	Dalmatian Pelican	Near Threatened	Winter	present

Table 2 - Bird populations meeting Key Biodiversity Area criteria present in Kaj Lake.

4.4. Fisheries

Gujarat has the longest coastline of any state in India, and fishing is an important economic activity in the region. The coastline of the Saurashtra peninsula accounts for 90% of marine fish landing in the state. In the coastal region close to the proposed offshore wind development zones, around Nava Bandar, Rajpara and Jaffrabad as in Figure 12, the traditional method of fishing with a dol net (similar to a bag net) contributes significantly to the fish catch in Gujarat (K. M. Sikotaria et al., 2018). This is a static gear type of fishing and is deployed in coastal waters between 6 and 12 nautical miles (Morgan, 2004). A dol net is a fixed tapering bag of length 12-14 metres which is anchored in a tidal stream to trap fish by interrupting swim lines parallel to the shore. As the tide recedes, the trapped fish can be collected. This method is used to catch a variety of species, notably Bombay Duck and shrimp, and is seasonal. The catch volumes have increased in recent year due to improved crafts and longer sailing periods, which has raised the risk of overfishing. Another traditional method, which is commonly deployed along this coast line, is the gillnet. This is a static net hanging in the water column which traps fish. Another significant method is trawl netting, where a large conical net is dragged through the water column, close to the sea bed, by a motorised boat. The landing centre at Veraval, located westwards along the coast from the offshore wind development zones, is the largest in Gujarat accommodating around 8000 boats and has a significant number of gill and trawl nets fishers (Rathod et al., 2021). The location of fishing grounds for trawl nets must be understood to identify any potential conflict with the offshore wind development zones.

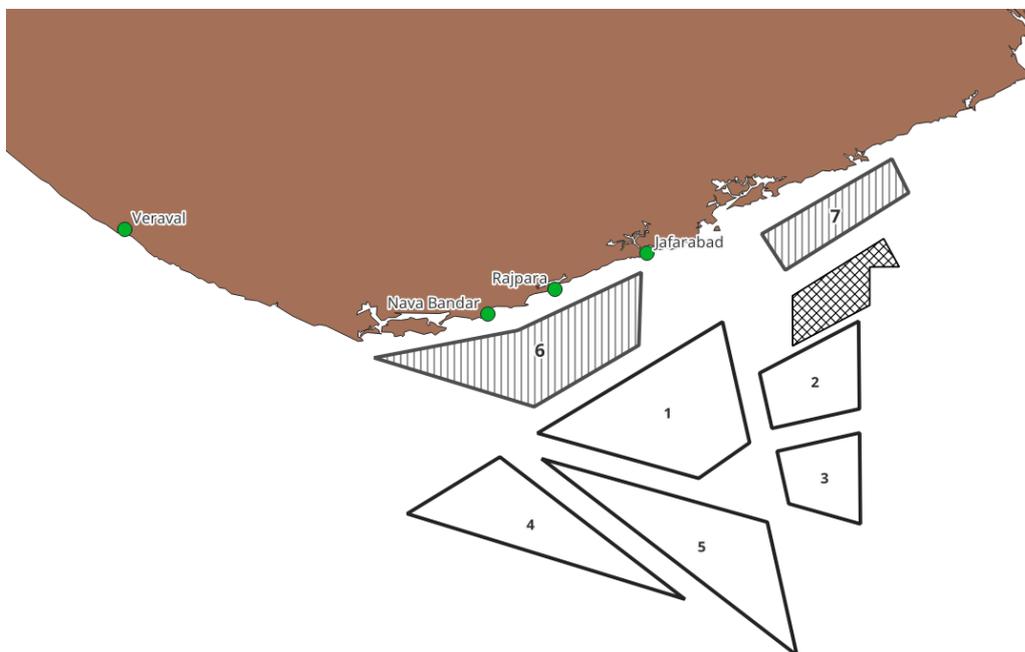


Figure 12 - Location of key fishing communities in coastal region close to offshore wind development zones.

Any development in the nearby coastal region, particularly nearshore wind farm development in zones 6 and 7, would have an impact on local fishing communities. Clarity is required on how fishing will be affected during the different phases of an offshore wind farm from construction through operation and ultimately decommissioning. A dialogue with local stakeholders is essential in understanding the impacts and developing mitigation strategies.

In parts of Northern Europe (Bonsu et al, 2024), the area of an offshore wind farm is restricted and thus excludes fisheries from the area and increases distances to fishing locations. The exclusivity is primarily due to the concern of the wind farms operability and the integrity of the electrical system from anchor drags and bottom contact fisheries damaging array- and export cables (Crown Estate, 2012). Other regulatory solutions include no-trawling/-anchoring zones around offshore cables, e.g. Denmark, UK. Complimentary to the regulation, the developer assesses burial risk to determine the necessary burial depth from a probabilistic perspective (Carbon Trust, 2015). This implies that it is to some extent possible for passive fisheries and pelagic fisheries to co-exist with offshore wind facilities, while limiting bottom contacting fishery activities drastically.

Depending on the specific fishing activity/equipment and development area, it is possible for the usage-types to co-exist. This can be implemented by early planning of fishing corridors between wind farms, transfer corridors through the wind farm to specific sites or specific burial depths of the wind farm's export cables (Bonsu et al, 2024). Another mitigating measure is compensation of lost revenue for affected fishery, which typically is the least favoured option for all parts.

4.5. Cables

Submarine cables are concentrated both in the Indian Ocean and Arabian Sea. The website by TeleGeography (<https://www.submarinecablemap.com/>) shows submarine cables in western coast of India and their landing point, where most of the cables are seen to originate from the coast of Mumbai. Note that the cables are only shown diagrammatically on the map, and do not represent the actual geographic route of the cables. From this information it is unlikely that these telecommunication cables pass through the proposed offshore wind development zones, however more precise location of the cable routing is required to confirm.

Crossing of submarine power cables and communication cables is a well-known issue, and rarely pose a significant risk to OSW development. Mutual agreement and settlement with the owner(s) of such cables must however be carefully planned and executed in due time to mitigate such risk. Examples of crossings are seen in the North Sea.

4.6. Oil and gas

Most up to date map of the blocks in this area. The fields from the first revision are still up to date according to the Global Oil and Gas Infrastructure spatial mapping (National Energy Technology Laboratory, n.d.).

The offshore area off the south coast of Gujarat falls within the Mumbai Offshore sedimentary basin, which is a Category-I basin with proven commercial productivity. This basin contributes nearly half of India's oil and gas production, with production starting in 1976. It has several active oil and gas fields, as well as further surveying taking place (Directorate General of Hydrocarbons, 2024, p. 32). Figure 13 shows, a map with the wells marked in yellow and new survey lines from the 2023-2024 campaign. It is clear that the Mumbai Offshore basin remains an active area in India's hydrocarbon extraction strategy.

**NEW 2D SEISMIC DATA ACQUIRED
UNDER EEZ SURVEY CAMPAIGN (2023-2024)
(79539 LKM SHOWN IN 'RED')**

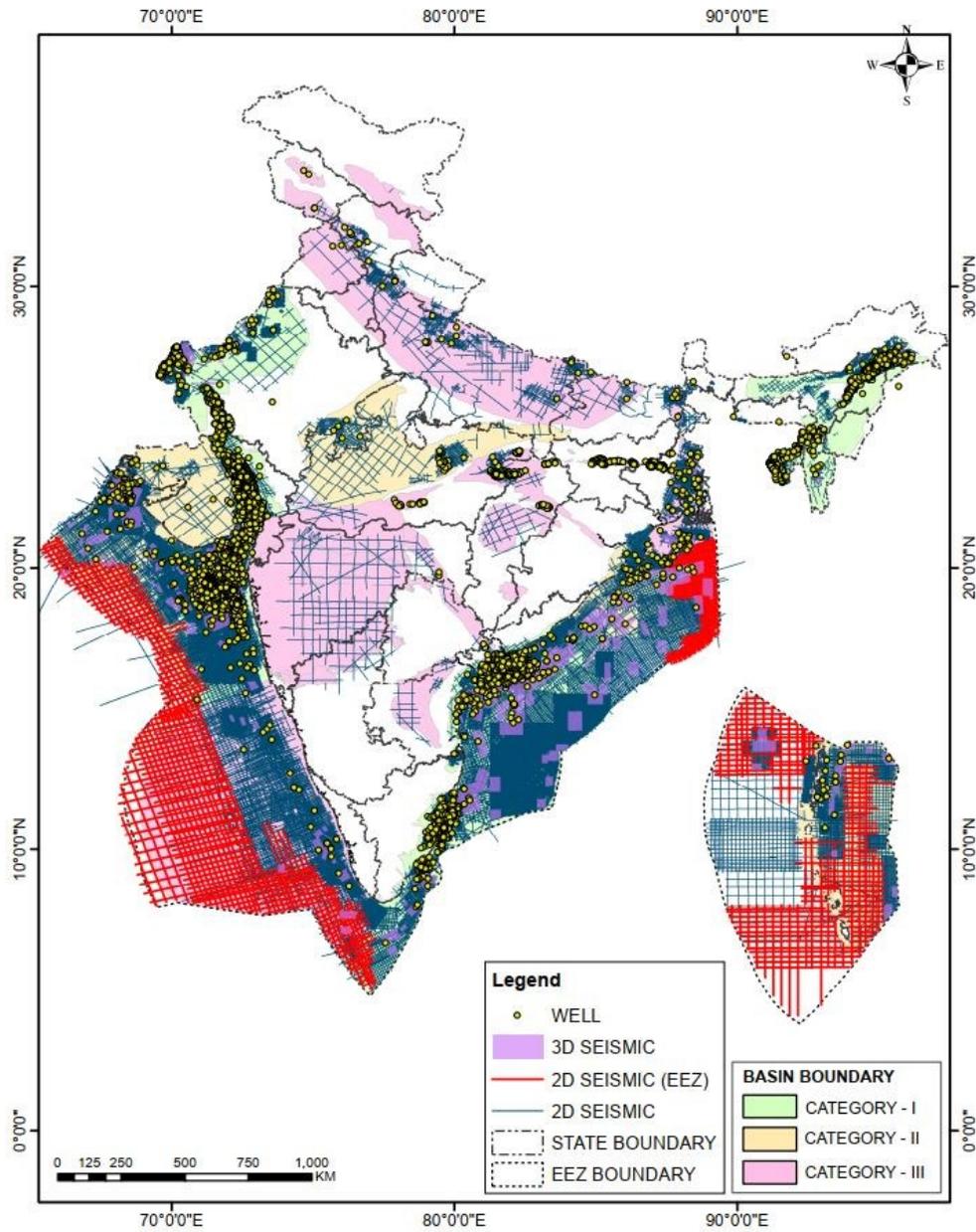


Figure 13 - Seismic survey data and wells across India and the offshore region.

The map in Figure 14 shows the proposed offshore wind development zones with the oil and gas basin and pipelines in the area. This reveals that there is a potential conflict in the eastern half of the area, should these basins be selected for hydrocarbon extraction in the future.



Figure 14 - Proposed offshore and nearshore development zones, with oil and fields, and pipelines marked.

The proposed offshore development zones share a border to the mid and south Tapti oil and gas field. The five platforms in this field ceased production in March 2016, however ONGC (Oil and Natural Gas Corporation Limited) are using the facilities to process gas from its nearby Daman and C-Series fields.

The Open Acreage Licensing Policy (OALP) offers blocks through a biannual bidding process. OALP bid round-III included a block in the Mumbai Offshore basin off the south coast of Gujarat which overlaps directly with the proposed offshore wind development zones (Directorate General of Hydrocarbons, n.d.).

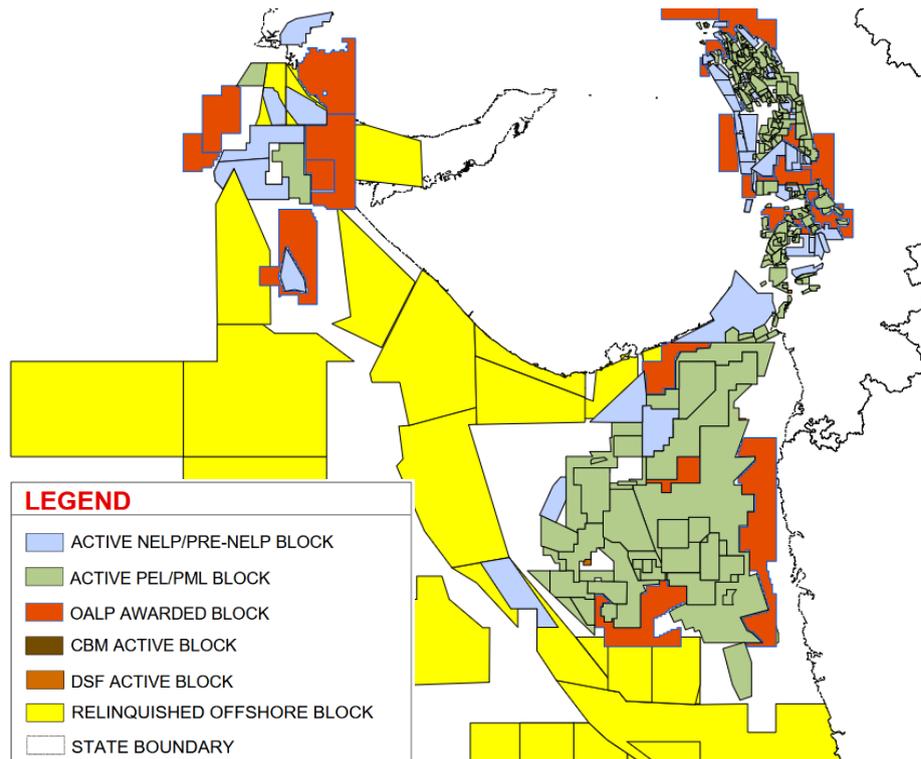


Figure 15 - Status of offshore oil and gas blocks off the coast of Gujarat.

The Special Discovered Small Fields (DSF), bid round 2024 includes two fields in the Mumbai Offshore Basin (C37 and B15), of which field C37 directly overlaps with the proposed offshore wind development sites, see Figure 16 (Directorate General of Hydrocarbons, 2024). The DSF bid round IV was launched on 15 April 2025, includes two fields (C-39-14 and C-23-9) in the Gulf of Khambhat, under the Mumbai Offshore basin, <https://online.dghindia.org/dsf/BidRoundIV>, which do not overlap with the proposed offshore wind development zones but are located nearby, see Figure 17 (Directorate General of Hydrocarbons, 2025).

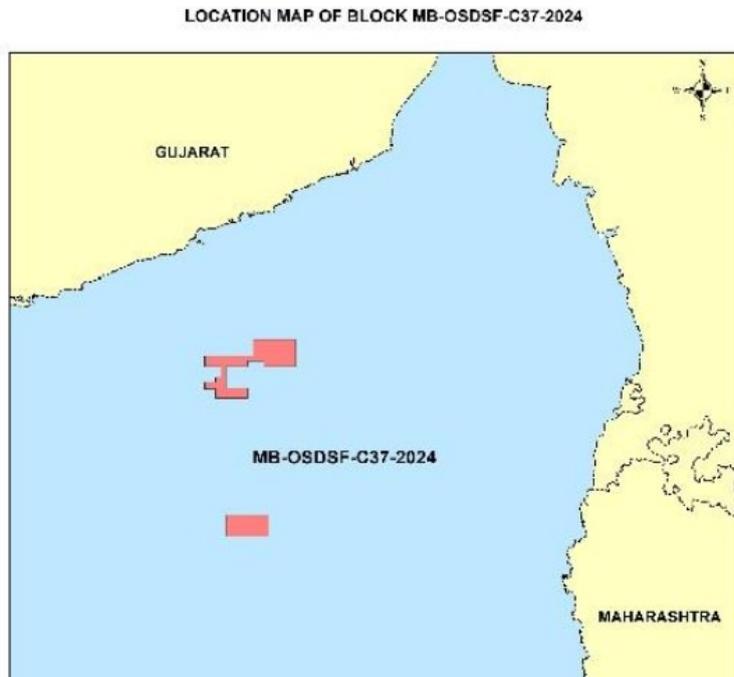


Figure 16 - Special Discovered Small Fields (DSF) bid round 2024 field C37.



Figure 17 - DSF bid round IV opportunities available (2025), showing two fields in the north, close to the offshore wind development sites (Directorate General of Hydrocarbons, n.d.).

<https://dghindia.gov.in/assets/downloads/56cef5d421448dghwebsite4.pdf>

Further exploration of the Diu formation is taking place, hence thorough investigations and early liaison with key stake holders within the oil and gas industry are required to understand if this presents a potential for a conflict in sea area usage (World Oil, 2024). As agreed in the revenue sharing contract of the described blocks, the co-existence of exploration and production of hydrocarbons and other substances and minerals are allowed by the Ministry of Petroleum and Natural Gas (MoPNG). Therefore, an assessment of operational interference, environmental impacts, and safety concerns between oil and gas and offshore wind development is required.

4.7. Raw material extraction

The Ministry of Mines has issued a notice inviting for tender for 13 offshore areas for mineral extraction (Ministry of Mines, 2025), these include three blocks off the coast of Gujarat for the extraction of lime mud. The three blocks each have an area of approximately 70 km², and the closest port is at Porbandar.

Limestone is one of the essential raw materials in the cement, and several other industries. In India, only 8% of the limestone resources are placed under the reserve category, of which 97% is of cement grade. Thus, India depends on imports to bridge the demand-supply gap of chemical-grade limestone. Efforts of Geological Survey of India (GSI) to locate alternate sources for limestone led to the discovery of enormous quantities of carbonate minerals called limemud from the continental shelf margin of the west coast of India where more than 172 billion tonnes of high-grade limemud have been discovered in 0.4–28.0 meter thick stratified sediment layers spread over an area of 18 000 km² (Adukadukkam et al., 2024). It is therefore likely that mineral extraction in this area will continue to be an important use case. The areas reserved for the first tranche of auctions lie directly to the west of the proposed offshore wind areas, with no direct overlap. The carbonate platform where limemud has been Identified does not overlap with the proposed zones, as shown in Figure 18.

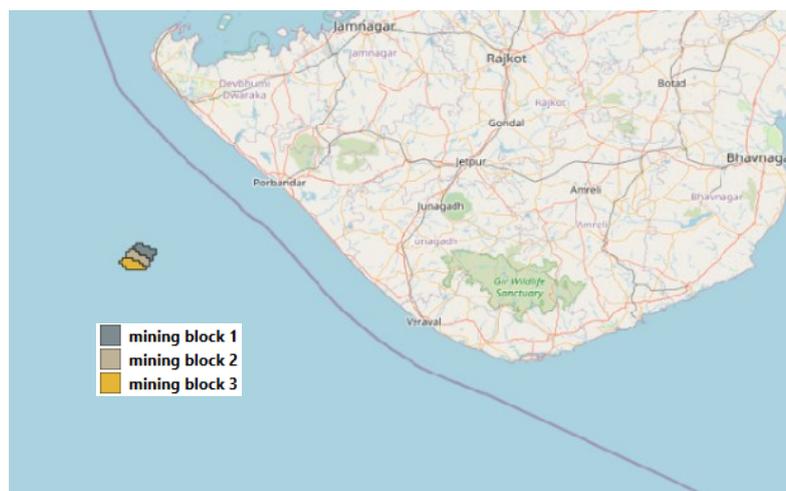


Figure 18 - Offshore mineral deposits off the Gujarat coast, showing areas rich in limemud. The location of the first three extractions blocks lies in the West Coast, near Porbandar. (Ministry of Mines, 2025).

4.8. Military

The first revision of this report on Marine Spatial Planning identified three areas which were not granted in-principle clearance from the Ministry of Defence. Two of the areas (G and H) are located on the western coast of the Saurashtra peninsula, which is not considered as part of this revision due to the less favourable wind conditions. The third area is located on the south coast of the peninsula (Zone C).

These areas are shown in Figure 19 in red, along with the new proposed offshore wind development zones in black. The 12 nautical mile coastal boundary is marked in yellow and the nearshore development zones are shown with a striped infill. The green shading is from the heat mapping exercise in section 3, where the darker shading indicated more favourable wind and water depths for wind energy development.

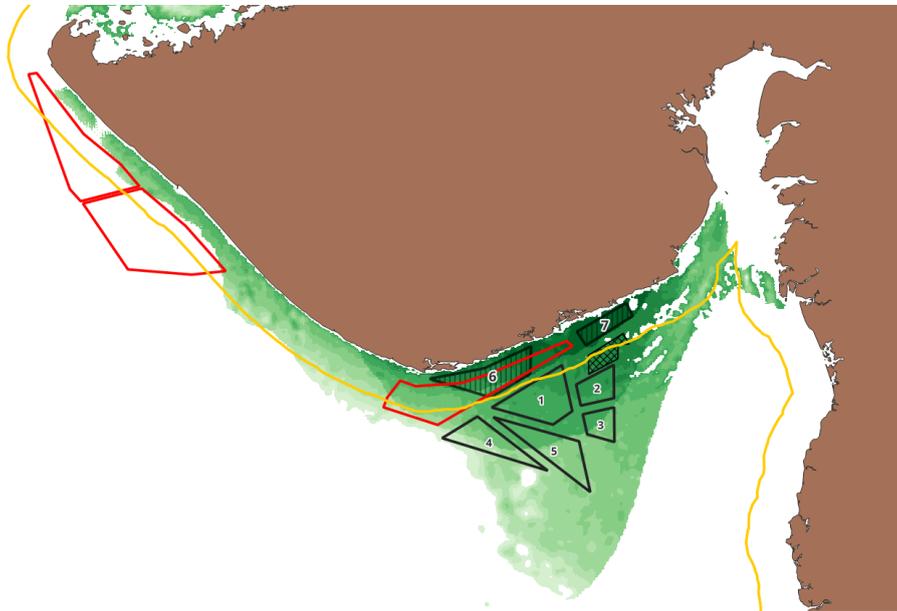


Figure 19 - Areas without in-principle clearance in red, new proposed offshore wind development zones in black. The 12 nautical mile coastal boundary is marked in yellow and the nearshore development zones are shown with a striped infill. Green shading indicated areas with favorable wind speeds and water depths for offshore wind development, darker areas are more favorable.

The map shows that the area to the south of the Saurashtra peninsula (Zone C) coincides with some of the most favourable conditions for wind energy development. It falls mostly within the 12 nautical mile coastal boundary, and overlaps in part with the proposed nearshore development zone 6. Zone 7 was not included in the previous revision of MSP in Gujarat, and therefore in-principle clearance has not been sought. The offshore zones 1-5 overlap mostly with the zones in the previous revision of MSP, which were granted in-principle clearance. If zones 6 and 7 are to be considered for development, a further discussion with the Ministry of Defence is required to understand if there is a possibility for a wind farm to coexist with the military use of the area, for

example through radar mitigation measures, or if there is an option to relocate the military activity in this area, for example training, to another area which is less favourable for offshore wind.

4.9. Aviation

The restriction zones around Diu airport are illustrated in Figure 20. The Airports Authority of India (AAI) states that clearance for buildings and masts is required within up to 20 km for Visual Flight Rules (VFR) Airports and up to 56 km for Instrument Flight Rules (IFR) Airports. Distances are measured from Aerodrome Reference Point (ARP) of nearest airport/s. If the site is located beyond these limits and if the height of the desired structure is below 150 m above ground level, then NOC for height clearance from AAI is not required. The National Institute for Wind Energy (NIWE) is required to take in-principle clearance from relevant Government of India authorities (Stage I Clearance) before offering an offshore wind block for bidding.

The small civilian airport on the island of Diu, is located close to the proposed offshore wind development zones. It is a small airport, with fewer than 10 scheduled arrivals/departures per day. The airport, and the height limitations are given in Figure 20, and the radius of clearance boundaries described above are marked in Figure 21. It shows that the nearshore zone falls partially within the airport restricted air zone, and therefore deployment of turbines is likely restricted within this overlap. However, even outside this 9km radius, clearance is still required according to various flight rules up to 56 km from the airport, which encapsulates the whole western nearshore development zone, and parts of three of the proposed offshore development zones. Therefore, it is advised to consider the permits and clearances required for these zones, based on the requirements outlines above.

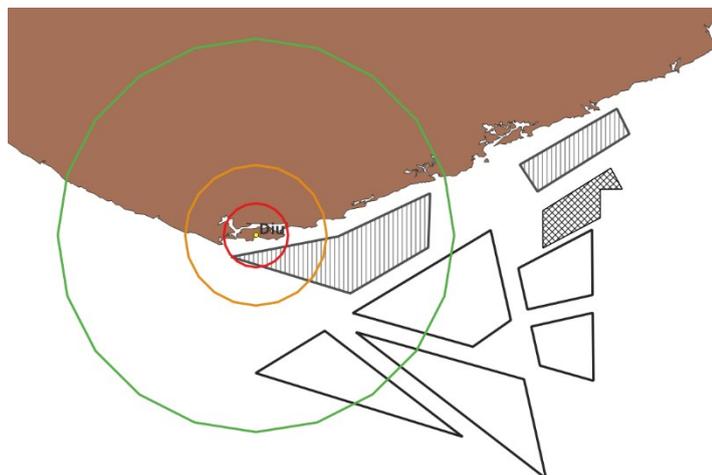


Figure 20 - The airport on the island of Diu. Concentric circles: Red 9.1 km radius, within which buildings must be below 119 m. Outside of this radius, specific clearance is required for Visual Flight rules within 20 km (Orange) and for Instrumented Flight Rules within 56 km (Green).

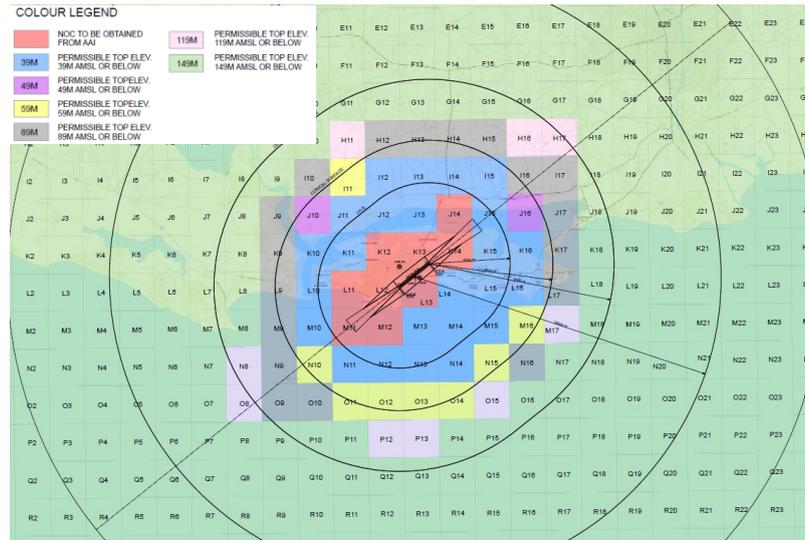


Figure 21 - Airport Authority of India- Restricted zone around Diu Airport (AAI, 2021)

4.10. Cultural heritage and tourism

The previous revision of this MSP report identified nine sites of archaeological interest along the coastline within close proximity of the initial proposed offshore wind development zones. This revision focuses on the sites of the southern coast of the Saurashtra peninsula, where the archaeological sites are concentrated on and around the island of Diu, shown in Figure 21.

Diu has a long and dynamic history, documented in 322 B.C. It's strategic location on the coast meant that Diu was for centuries one of the leading ports of Western India, playing an important role in the linking western India to the rest of the subcontinent, East Africa and the Persian Gulf. It is the site of a massive fortress built in the 16th century. Given the nature of the history of Diu, there may be submerged heritage in the surrounding region (District Administration of Diu, n.d.; Cardoso & Pombo, 2018).

Today, Diu has a small airport with few daily flights, but is otherwise outside of any major transportation routes. Diu is an extension of Kathiawad Cultural Zone, and is regarded as a place for relaxation and tourism with several beaches and sites of historical interest. This may present a challenge to nearshore wind farm development in particular, as the visibility of wind turbines could meet opposition from the local tourism industry.

4.11. Seismic activity

The state of Gujarat lies in one of the highest seismic risk zones in India, it has three distinct geological regions with varying subsurface structures, and therefore different seismic potentials, with the southern part of the Saurashtra peninsula have a lower potential than the north of Gujarat. However, the Saurashtra region has experienced significant earthquakes in the past (*P. Choudhury et al., 2018*).

The map below in Figure 22 shows the magnitude of the peak ground accelerations across Asia, the state of Gujarat is circled in black. The southern part of the state has a low peak ground acceleration, which indicates that seismic activity will not likely present a barrier to offshore wind development.

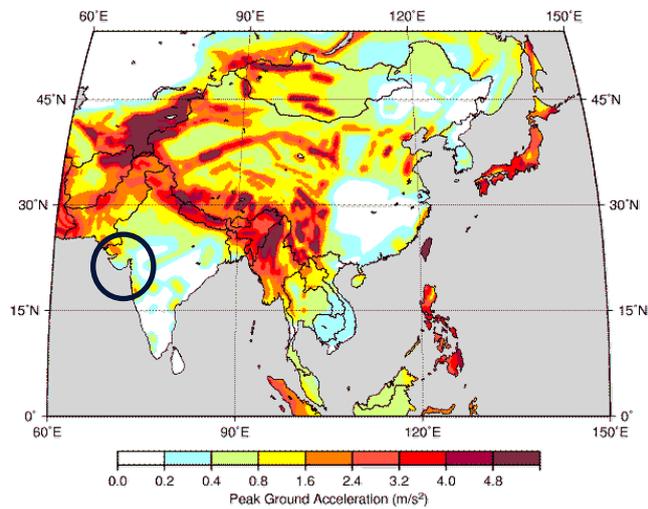


Figure 22 - Peak ground accelerations across Asia, the state of Gujarat is circled in black (Swiss Seismological Service, n.d.)

A more detailed seismic activity map for the Gujarat area is shown in Figure 23. Note that most of the earthquake activity is recorded in the inland area, which falls under seismic zone III as per the Bureau of Indian Standards (BIS) seismic zone map. Furthermore, the Saurashtra region is vulnerable to earthquakes of magnitude ~6.0, and in the past, a magnitude 5.7 earthquake was reported from Paliyad, Bhavnagar. Note that site-specific seismic hazard studies are necessary to ensure proper seismic design, as per the BIS guidelines (Bureau of Indian Standards, 2016).

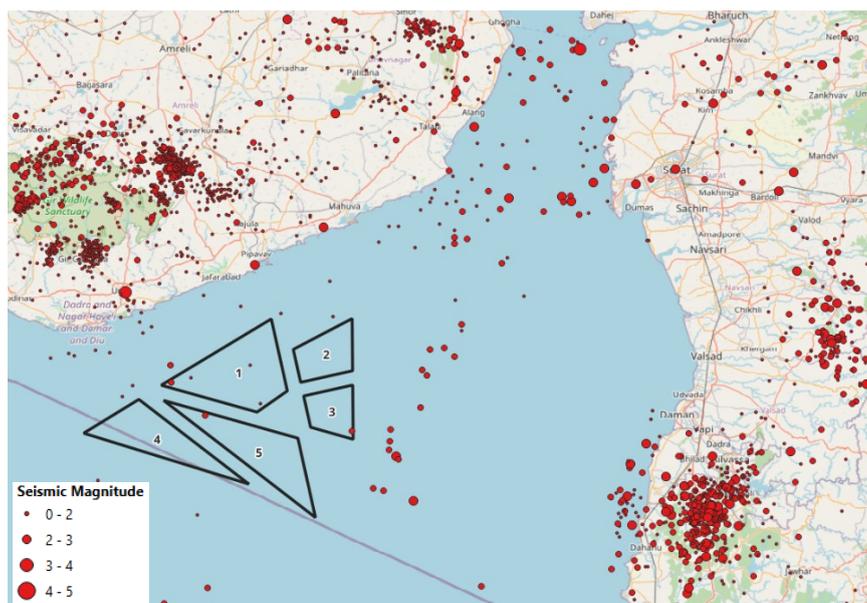


Figure 23 – Recorded seismic activity in the Gujarat area.

5. Site suitability

5.1. Wind climate

The Global Wind Atlas combines model and observation to generate wind speeds values across the globe and is a useful tool to indicate regions with a high potential for wind power development. The map in Figure 24 shows the annual average wind speeds at an elevation of 150m with the proposed offshore wind development areas overlaid.



Figure 24 - Average annual wind speeds (m/s) at 150 m elevation from the Global Wind Atlas with the propose offshore wind development zones overlaid. Offshore (1 - 5), nearshore (6, 7) and the VGF site (hashed).

A LiDAR based offshore measurement campaign was commenced on November 2017 in Zone B3 (VGF site), Gulf of Khambhat, off Gujarat coast, which is first of its kind in the country. The LiDAR is installed on a monopile structure approximately 23 km from the coast, close to the VGF site. Based on the real-time LiDAR measurements, the period from November 2017 to November 2018 data analysis report namely “First Offshore LiDAR Wind data analysis report” (NIWE, 2019) has been hosted in NIWE website for the benefit of the offshore stakeholders (National Institute of Wind Energy, 2018). In continuation with the First Offshore LiDAR Wind data analysis report, the second year of data for the period from December 2018 to November 2019 has been analysed and reported again by NIWE and is available on the website (National Institute of Wind Energy, 2019). This section will highlight the main findings from that report in terms of wind climate, but more details can be found in the original reports.

It should be noted that there are periods of low measurement availability from Nov-2017 to Jan-2018 and May-2019 to Nov-2019 and there is no data from 13-Jul-2018 to 12-Sep-2018. Data in

these periods has been synthesized by using (Measure-Correlate-Predict) MCP technique. Under the MCP method, sector-wise daily mean wind speed data (12 sectors) from the LiDAR measurement (40m to 200m height) were correlated with the concurrent data of Jafarabad coastal mast measurement (100m height, extrapolated to 150m following MEASNET guidelines) by using LLS (Least Linear Square) algorithm. The correlation coefficient of determination (R2) between LiDAR data and Coastal mast data was estimated above 0.80, which seems to be a good correlation. Correlation coefficient of determination between LiDAR data and coastal mast data can be seen in the original reports. No estimation of the uncertainty is given.

The LiDAR location allows a good representation of the wind climate in the site area. Based on the synthesized/validated results, the mean wind speed and mean wind power density summary of the data collected can be seen in Figure 25.

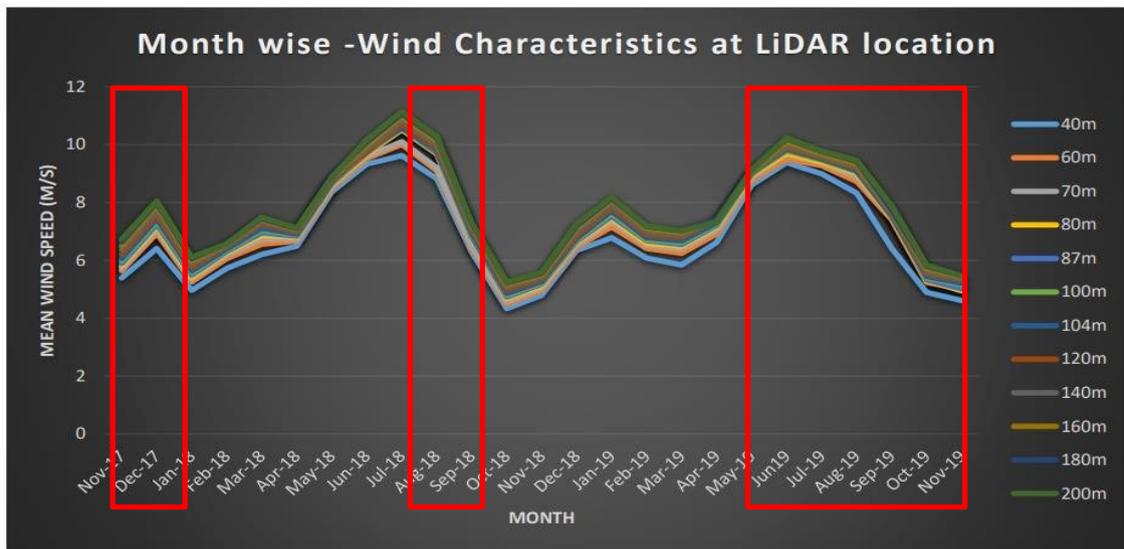


Figure 25 - Mean wind speed measurements on a monthly basis (NIWE, 2019). Note the periods marked in red do not have complete measurements and use the Measure-Correlate-Predict technique to estimate the wind speed.

The average wind speed observed in LiDAR measurements confirms the wind atlas assumptions taken in the rough screening section for the OWF zones in B3 area, which were observed at 150m above sea level height to be between 7.5 m/s and 8 m/s. At 160m above sea level the yearly average wind speed is measured as 7.81 m/s between Nov-2017 and Nov-2018, and as 7.79 m/s between Dec-2018 and Nov-2019. The uncertainty of the LiDAR measurements is expected to be lower than the mesoscale model used in the Global Wind Atlas, however using the MCP technique adds a level of uncertainty.

Wind rose for all measured heights can be seen in Figure 26 for first year measurements and shows that the primary wind direction is from the south-west, followed by a NNE (north of north-east) wind.

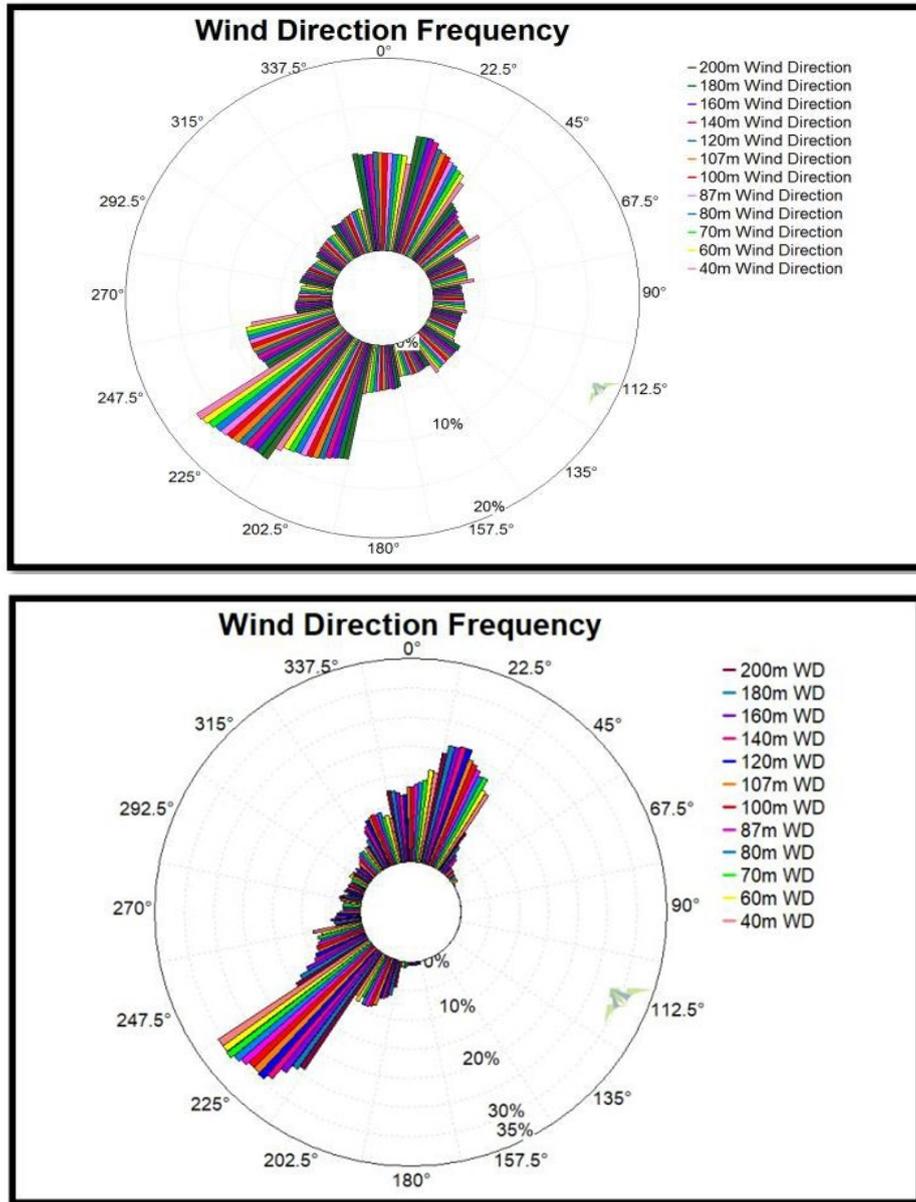


Figure 26 - Wind frequency rose for all measured LiDAR heights between Nov-2017 and Nov-2018 (upper) and Dec-2018 to Nov-2019 (lower) (NIWE, 2019).

The annual average wind speed values observed off the Gujarat coast show consistency between the mesoscale model used in Global Wind Atlas and the LiDAR measurements. When wind climate characteristics on a monthly basis are taking into consideration, LiDAR measurements show that the wind speeds are higher between months of May and August compared to the rest

of the year as can be observed in Figure 25. This difference causes the annual average wind speed to be close to 8 m/s, but actually the wind speeds for the rest of the year range from 5 m/s to 7.5 m/s. This observation provides an indication about the WTG type that is more suitable to lower wind speed profiles for offshore wind projects in the region.

5.2. Sea state

The sea state conditions, including waves, current and tidal water levels, are important considerations in designing offshore wind farms. These factors will also play a significant role in the installation process, where specific sea states may restrict or prohibit access for installation vessels. During wind farm operation, access to the site for operation and maintenance will also depend on sea state conditions.

As part of the FOWIND study a metocean study was completed which included the collection of data from various sources including models and measurements (GWEC et al., 2018). Results in Table 3 are presented in the form of all-year omni-directional extremes of wind speed, wave height, water levels and currents for the return periods of 5, 10 and 50 years, for non-cyclone and cyclone conditions where applicable. Tidal levels are given in metres with respect to both Mean Sea Level and Low Astronomical Tide. The location considered for this study is: 20.42°N, 71.38°E, which falls between zones 1 and 5 in the proposed offshore wind development zone.

Return Period [years]	Non-cyclone season			Cyclone season		
	5	10	50	5	10	50
SEA STATE (3-HOUR)						
Maximum individual wave height [m]	8.6	9.5	11.5	8.2	9.8	12.5
Associated period [s]	11.2	11.4	11.8	8.6	9.4	10.6
Associated wave length [m]	171	176	188	115	134	164
Significant wave height [m]	4.8	5.3	6.6	4.7	5.6	7.1
Zero crossing period [s]	8.6	8.8	9.1	7	7.7	8.6
Peak energy period [s]	12.1	12.4	12.8	9.3	10.2	11.5
WATER LEVELS						
Wave crest elevation [m]	4.9	5.6	7	4.7	5.7	7.6
Tidal rise [m]	3.1	3.1	3.1	3.1	3.1	3.1
Storm surge [m]	0.4	0.4	0.5	0.2	0.5	1.3
Safety margin [m]			1.5			1.5
Minimum airgap [m]			12.2			13.5
CURRENT						
Total surface current [m/s]	2	2.1	2.3	2.2	2.3	2.7
Current at 25% of water depth [m/s]	1.9	2	2.1	2	2.2	2.5

Current at mid-depth [m/s]	1.7	1.8	2	1.8	2	2.2
Current at 75% of water depth [m/s]	1.5	1.6	1.7	1.6	1.7	1.9
Current at 1m above seabed [m/s]	1.1	1.2	1.3	1.2	1.3	1.4

Table 3 - Omni-directional extremes at return periods of 5, 10 and 50 years in both cyclone and non-cyclone seasons

Tidal Levels [m]		relative to MSL	relative to LAT
HAT	High Astronomical Tide	1.77	3.67
MHWS	Mean High Water Springs	1.2	3.1
MHHW	Mean Higher High Water	1.13	3.03
MHW	Mean High Water	0.85	2.75
MHWN	Mean High Water Neaps	0.53	2.43
MSL	Mean Sea Level	0	1.9
MLWN	Mean Low Water Neaps	-0.49	1.42
MLW	Mean Low Water	-0.87	1.04
MLLW	Mean Lower Low Water	-1.2	0.71
MLWS	Mean Low Water Springs	-1.25	0.65
LAT	Low Astronomical Tide	-1.9	0

Table 4 - Gujarat Tidal Levels (m)

Measurement and forecast data for sea states in the region are also provided by the Indian National Centre for Ocean Information Services. A Wave Rider buoy is installed off the coast at Veraval, measuring sea state data and a coastal high frequency radar is installed at Jegri measuring current (Indian National Centre for Ocean Information Services, n.d.; Indian National Centre for Ocean Information Services, n.d.).

5.3. Seabed conditions

The map in figure 27 shows the water depth in the Gujarat offshore region with the proposed offshore and nearshore development sites marked. The water depth ranges from 0 to 50m. 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 characterised by a superficial clay layer with weak shear strength, followed by sand layers which are relatively denser, at various depths beneath. A desk-based review of the area was carried out as part of the FOWIND project, the results of which are summarised in table 5.

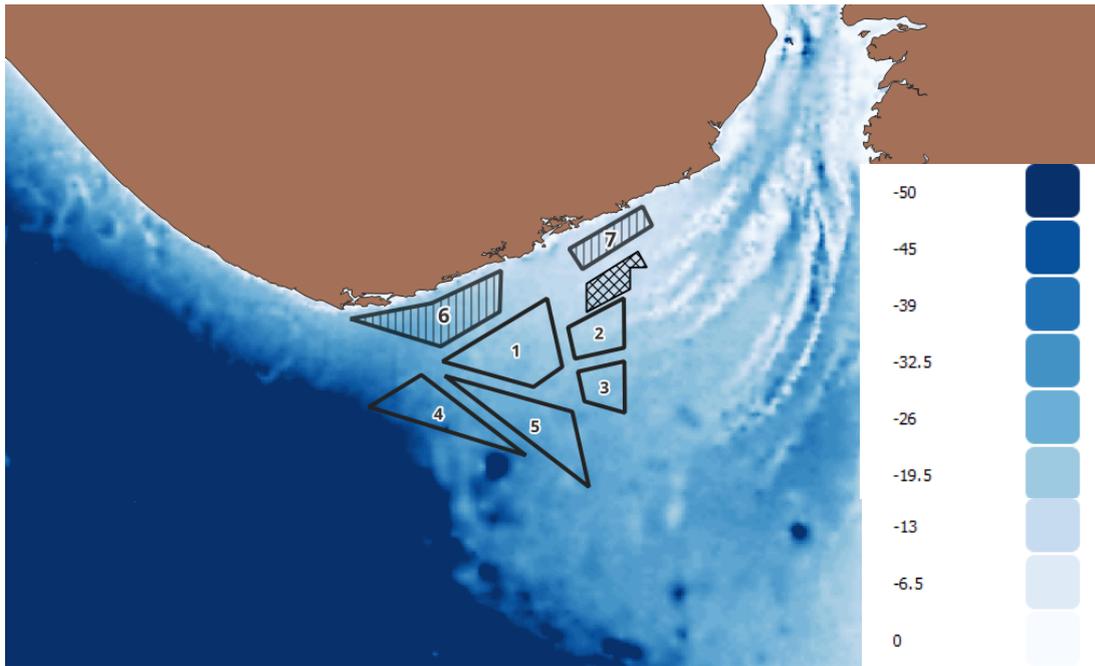


Figure 27 - Water depth (m) in and around the proposed development zones offshore (1 - 5), nearshore (6, 7) and the VGF site (hashed).

	Zone 6 (overlap with previous Zone C)	Zones 1, 4 and 5 (overlap with previous Zone A)	Zones 2 and 3 (overlap with previous Zone B)
Bathymetry	20 to 30 m Shallowest closest to coast	15 to 50 m Shallowest closest to coast. Deepest at western edge	0 to 30 m Shallowest in the nearshore zones in north-east where there are linear sandy shoals.
Stratigraphy	Clay down to 45 m with occasional laminations of sand below 20m depth.	Superficial clay layer from 20 to 40 m, followed by interlaid strata of sand and clay down to 120 m	Superficial clay layer from 10 to 35 m, followed by sand down to 50 m
Shear strength	Very soft at the seabed becoming firm with increasing depth. Sand layers expected to be medium to dense.	Very soft at the seabed to firm at the interface with the sand layer	Very soft at the seabed to firm at the interface with the sand layer which is medium to very dense.

Table 5 - Indicative geotechnical descriptions from desk-based review from 'FOWIND'* ref

Weak upper layers of seabed preclude the use of gravity-based foundations, and therefore monopile and jacket foundations are considered more suitable. Detailed geotechnical surveys are required to create a soil profile which will be used in the design of foundations. Various factors influence the applicability and cost of the different types of foundation such as the required penetration depth, the footprint, the weight of steel and the structural natural frequency.

The movement of the sandy deposits (levees, bars and shoals) can present a challenge to foundation design if conditions are expected to change over the lifetime of the structures, changing the seabed strength and influencing the structures' natural frequencies.

5.4. Grid and electrical infrastructure

A report on the power evacuation infrastructure for offshore wind farms in India details a preliminary concept design of a 500 MW offshore wind farm in zone B3 (Centre of Excellence for Offshore Wind and Renewable Energy, 2024). This includes an offshore substation located at the edge of the site nearest the coast, with an AC export cable of 21 km before reaching landfall, followed by an onshore cable of 12 km to Mahuva Onshore Substation as illustrated in Figure 28. This concept is based on connection to an existing 220 kV substation, however. The concept study also included a proposed turbine and array cable layout, however surveying and further planning is required by the developer. Close attention must be paid to the coast regulation zones at and around the landing point. The export cable would pass through the intertidal zone and close to a protected mangrove area surrounded by a buffer zone, *Reference SHEET NO: GJ 40, GRID NO: F 42 R 12/SE at <https://czmp.ncscm.res.in/#main-map>* (National Centre for Sustainable Coastal Management, n.d.).

At the landfall, a Transition Joint Bay is where the connection between the on- and off-shore cable is made. This can either be buried directly or placed into a preinstalled duct. Consideration is required to ensure this transition is not subject to thermal bottlenecks, whereby the heat from the cable is not sufficiently dissipated reducing the effectiveness of the cable.

The link from the landfall to the onshore substation can be either buried or overhead. The decision will depend on existing land use, budget, environmental constraints and construction permits.

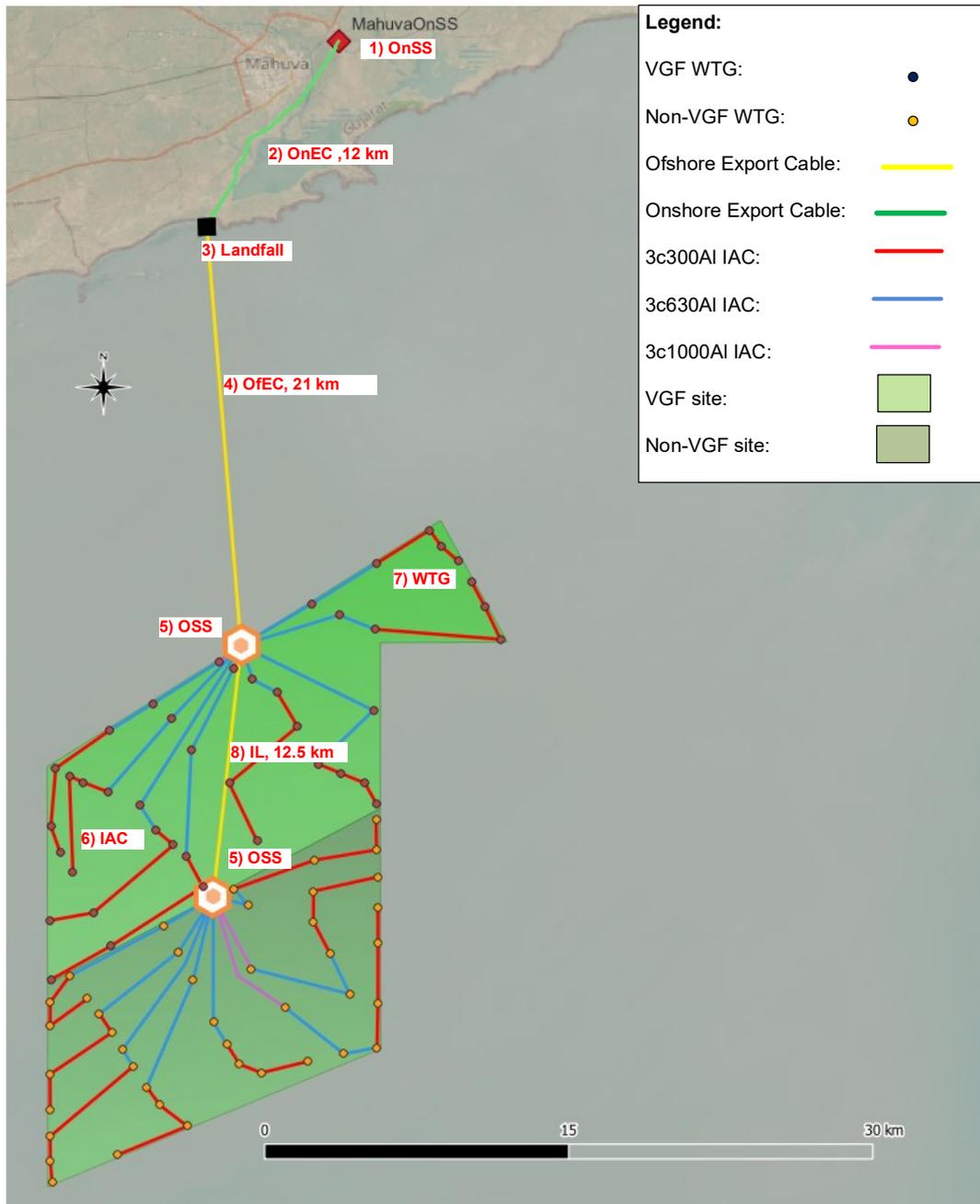


Figure 28 – Proposed cable layout for conceptual wind farm in VGF Zone B3, including export cable, landing point and onshore cable.

5.5. Ports and logistical infrastructure

Offshore wind farm development and operations requires specialised port infrastructure. Construction ports for bottom-fixed foundations present constraints due to the associated challenging logistics. Large scale ports are often upgraded and adapted in order to meet these requirements, where new dedicated infrastructure is not feasible. In contrast, operation and

maintenance (O&M) ports have modest technical requirements and should be located as close as possible to the offshore wind farm they serve. Small local ports and fishing harbours can often be utilized with minimal adaptations.

In 2024, the Indian government approved a Viability Gap Funding (VGF) scheme for offshore wind energy projects, allocating a total of ₹7,453 crore (approximately USD 0.89 billion). This includes ₹6,853 crore for the installation and commissioning of 1 GW of offshore wind energy projects—500 MW each off the coasts of Gujarat and Tamil Nadu—and ₹600 crore to support the upgrade of two ports to meet logistics requirements for these projects.

The current ports under consideration to accommodate offshore wind development for the designated offshore wind farm zones in Gujarat is likely to be either Pipavav Port or Deendayal Port (formerly Kandla port). See figure 29.

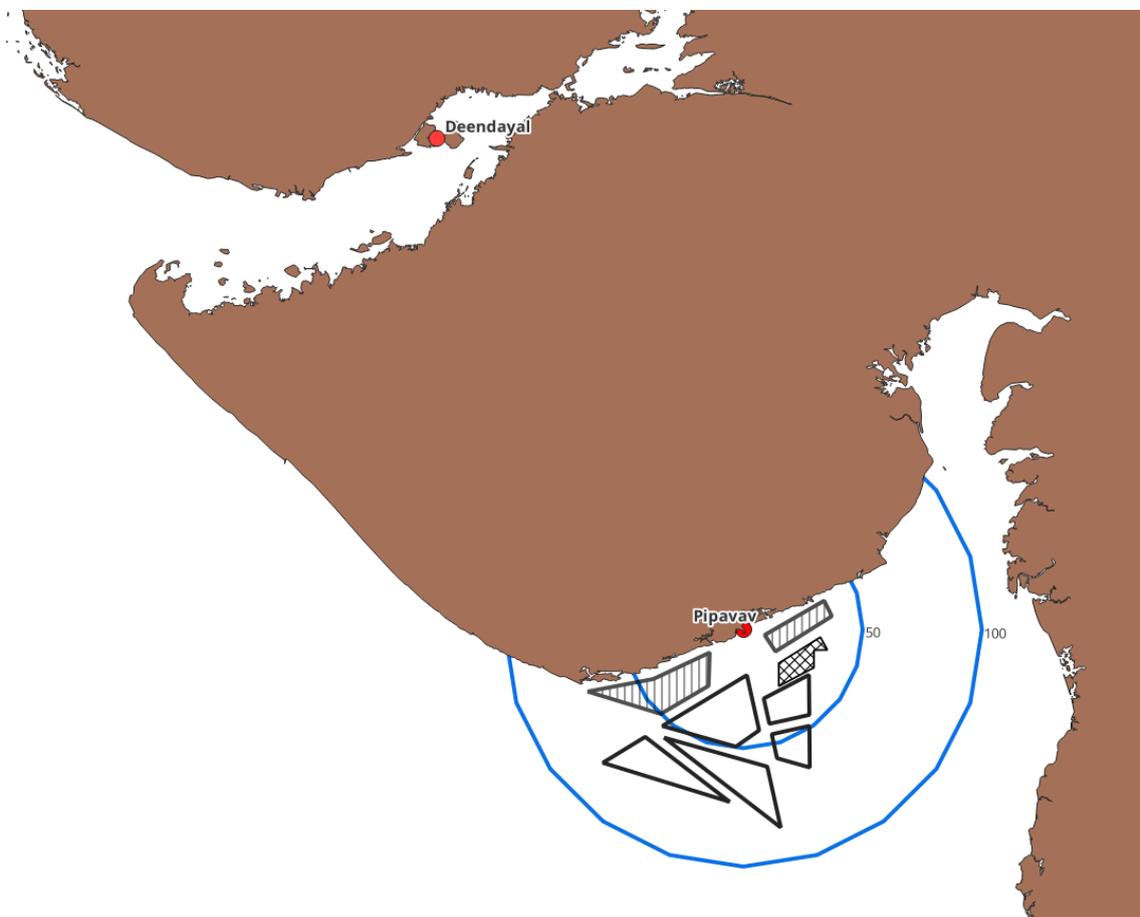


Figure 29 - The ports of Deendayal and Pipavav shown in relation to the proposed offshore wind development zones, with distance rings shown in blue (km).

5.5.1. Construction Port

The Centre of Excellence and consultants from COWI conducted a port study, which identified Pipavav as the most suitable port for upgrading to support offshore wind development, including construction, installation, and operation and maintenance, at the designated VGF site zone B3 in Gujarat. The screening and port study identified other potential construction, installation and O&M ports, including Hazira, Porbandar, Mundra, and Deendayal (formerly known as Kandla Port), but based on the criteria and requirements, Pipavav was selected (Centre of Excellence for Offshore Wind and Renewable Energy, 2023).

Pipavav Port, located directly adjacent to the Gujarat offshore wind zone, is a multi-use port operating under a public-private partnership model. It lies within close proximity to the proposed offshore wind development sites, which are all within 100km. With a considerable yard area of 630 hectares, reasonable berth length and depth, depth at channel entrance and harbour entrance width, Pipavav meets all requirements in terms of navigation, space and proximity. The port will require major upgrades. It currently lacks an adequate berth layout to support loadout activities, and the quay access bridges are limited to a width of only 10 meters. Establishing a dedicated loadout area will necessitate significant modifications to the existing terminals, including the potential use of part of the container terminal. Furthermore, if a new terminal is to be developed, dredging is likely also be required.

Deendayal Port is a multi-cargo port located in the Gulf of Kutch, and is one of India's major ports. In contrast to the other ports, Deendayal Port would not require the development of a purpose-built terminal, as it has some berths which are technically suitable for offshore wind operations. Primary improvements would be the retrofitting of the existing terminal structures to accommodate nacelles and pre-assembled towers.

The port has natural tidal protection during the monsoon season and is navigable in all weather. Deendayal is located between 500 and 600 km from the proposed offshore wind development sites, which will introduce long transport times and associated costs when installing wind farms.

For further assessment of the technical modifications, timelines and costs associated to these ports, refer to the port study (Centre of Excellence for Offshore Wind and Renewable Energy, 2023).

5.5.2. Operation & Maintenance (O&M) Port

Operating wind farms require regular maintenance to minimize downtime and maximize the generation of electricity through preventative and corrective maintenance. Operation and Maintenance strategies must consider access to the asset, transit time and the conditions in which a turbine can be reached, as well onshore logistics such as availability of parts, services and

personnel. O&M ports much have facilities such as offices and accommodation for staff, and a suitable berth for the required crew and maintenance vessels.

For Gujarat's B-3 OWZ, Pipavav is preferred as the primary O&M port due to its proximity, sufficient water depth and its natural sheltered area. Additionally, the presence of local industry makes it more likely that appropriate workforce would be available.

6. Site identification and conceptual planning

The heat mapping, Figure 3 from Section 3 has been used to rank the identified development zones according to their likelihood to give the lowest Levelized Cost of Electricity based on the two core physical parameters: wind speed and water depth. The sites are listed in order from most to least favourable in table 6. Following one of the assumptions from the strategy paper, this report will use an installed capacity density of 5 MW per km² within the sites, the estimated installed capacity in GW is also given in table 6.

The nearshore zones 6 and 7 present the best wind and water depth conditions, however it is clear from this study that these zones have a high level of potential for conflict. Both zones lie in more environmentally sensitive regions in terms of marine and bird life, as well as proximity to sensitive ecosystems such as mangroves. Zone 6 also conflicts with height restrictions with the airport at Diu, and was not granted in-principle military clearance. This stretch of coastline in Gujarat is a highly productive fishing area, with several fishing villages and landing centres situated along the coast. The types of fishing that takes place, from fixed net methods, to trawling, may not be compatible with development in these nearshore areas. If nearshore wind development is to be considered further, then careful stakeholder analysis and mitigation strategies will be required.

When looking at the offshore zones (outside the 12 nautical mile coastal boundary), the site already selected for development, and with VGF allocation, is the most favourable, followed by zones in the order 2, 1, 3, 5 and 4, due to the increasing water depth and decreasing wind speed moving further offshore. These five zones are estimated to have a total capacity of 11.8 GW, based on a density of 5 MW per km². This estimate is only indicative and is dependent on the final layout and density selected, and any requirement for navigation corridors within the zones which may reduce the development area.

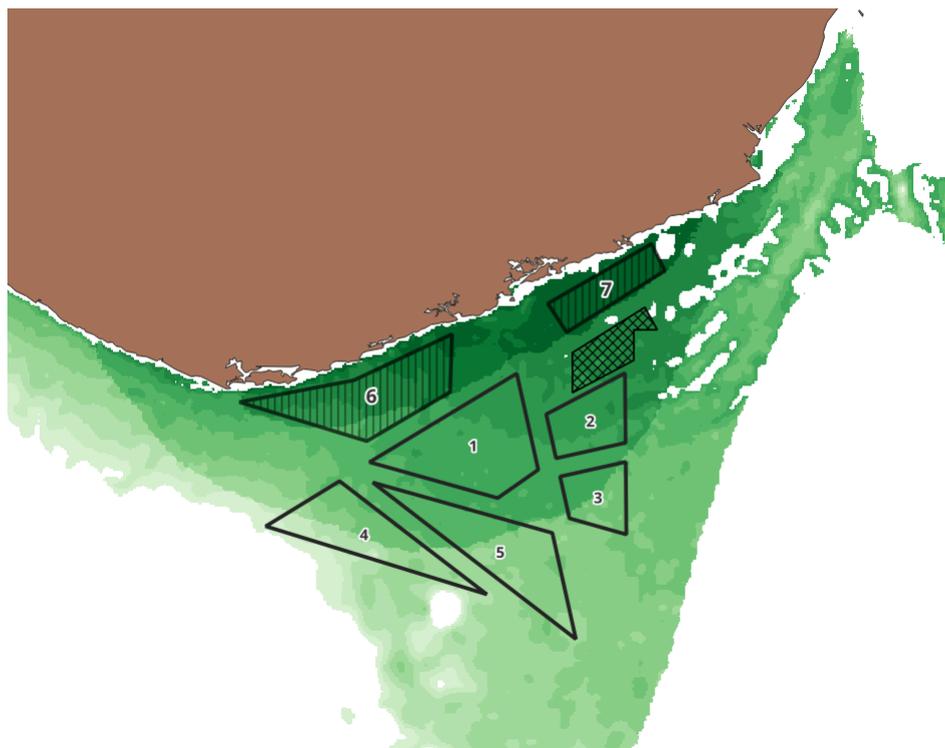


Figure 30 - Proposed offshore wind development sites considered as part of this MSP study, overlaid on top of the heat map indicating most favourable wind speeds and water depths in dark green.

Zone	Area (km ²)	Heat map index (-)	Annual mean wind speed at 150m (m/s)	Water depth range (m)	Capacity (GW) at 5MW/km ²
VGF	201	11.87	7.83	10 - 16	0.5*
7 [†]	254	14	8.12	10 - 15	1.3
6 [†]	623	11.81	8.13	11 - 28	3.1
2	294	10.78	7.65	13 - 22	1.5
1	714	10.2	7.75	15 - 26	3.6
3	236	8.73	7.48	18 - 27	1.2
5	602	7.67	7.47	22 - 32	3
4	506	6.41	7.51	28 - 49	2.5

Table 6 – Proposed offshore wind development sites, ranked in order of favorability based on wind speed and water depth.

*VGF site zone B3 has been tendered with a capacity of 0.5 GW, which correspond to a power density of 2.5 MW/km².

[†]Nearshore zones are subject to significant restrictions and conflicts with aviation, military, environment, fisheries and tourism.

Note 1: The desktop study from FOWIND shows a similar shear strength of soil conditions across all zones, so it will not change the ranking, hence not included in this ranking.

Note 2: Heat Map Index, see annex B for methodology.

Note that, although Gujarat has an offshore wind potential of approximately 37 GW based on an initial assessment by NIWE, in view of the restrictions and limitations presented in this report, only the offshore development zones 1 – 5 are considered viable. These have a potential installed capacity of approximately 11.8 GW. These zones are reasonable for early deployment and can support future expansion in other areas.

Typical offshore wind farms currently have a capacity of 1 GW, with many examples of larger sites worldwide. This size introduces an economy of scale to developers and governments. It could therefore be advantageous to divide the proposed zones into further subzones, with capacity in the order of 1 – 1.5 GW.

The design of a large wind farm cluster must include consideration of how the power evacuation infrastructure will be designed; the offshore substations, export cables, landing arrangements and grid connections. There may be opportunities to share infrastructure if it is designed to accommodate multiple sites, or multiple connection points. The capacity of the grid to receive a large input of power during periods of high wind speeds is fundamental to a successful wind farm; periods of curtailment will drive up the cost of electricity and limit the efficiency of investment in the infrastructure.

When generating power, wind turbines introduce a wind speed deficit, or wake, downstream as they extract energy from the wind, which can impact the generation capacity of downstream turbines. In a large cluster of wind farms, such as these proposed sites in Gujarat, it is important to consider how the wakes from neighbouring sites will interact as this will impact the business case for each site. This may mean implementation of guidelines for turbine spacing and layouts, or introducing buffer zones between sites to allow wind speed recovery.

7. Recommendations

This study on Marine Spatial Planning of offshore Gujarat has focussed on the potential for offshore wind development given the regulation, constraints and restrictions due to a broad range of stakeholders. Starting from the available information on wind speeds and water depths, potential development zones have been marked before examining other use cases and restrictions in and around these areas. The study has separated the zones into near- and off-shore using a coastal boundary of 12 nautical miles – marking the jurisdiction of the State government within the boundary, and the federal government beyond.

The timeline shown in figure 31 outlines the steps required from site identification through to wind farm construction. This study has identified sites with potential for offshore wind development, and the timeline indicates approximately 10 years are required from this stage to construction. The next step, prior to launching a tender are to ensure a political decision has been made to reserve space at sea for offshore wind development. This is followed by a series of environmental assessments such as Strategic environmental assessment (SEA) and environmental impact assessment (EIA) and site investigations, both offshore and at the onshore landing point and connection to the grid. The intention is to prepare in advance of the tender by gathering data and information early to de-risk the project in order to keep the cost down and encourage a lower bid price. Many of the processes can be run in parallel, for example the environmental assessments and the preliminary investigations of the on- and offshore sites.

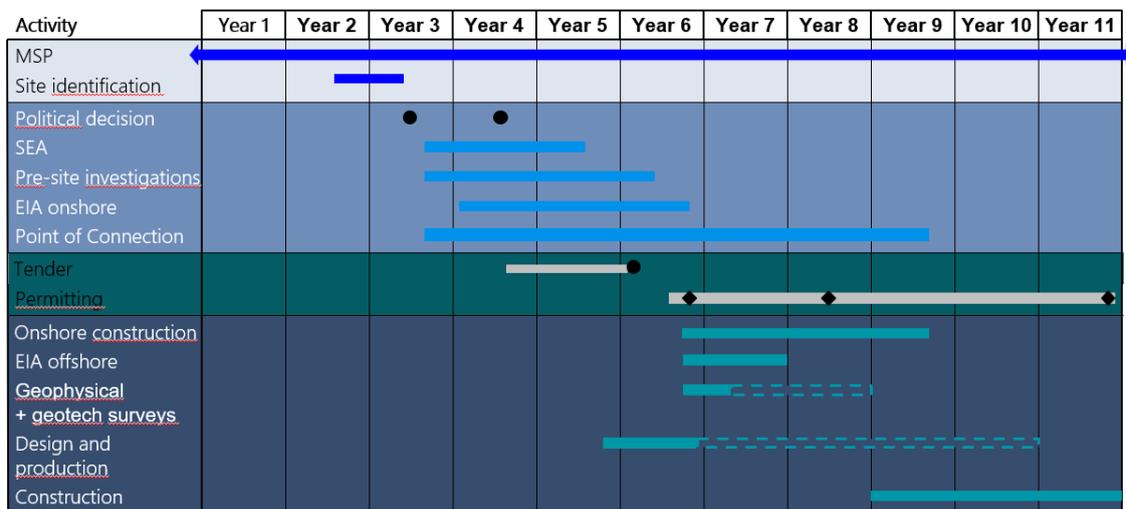


Figure 31 – Example timeline for an offshore wind project from site identification to construction.

It is recommended to follow the steps outlined in this timeline, which will need to be accelerated in order to meet the targeted installed offshore wind capacity set by the Government of India. The key recommendations are described below:

1. Focus on offshore rather than nearshore wind development

The study has revealed significant obstacles for offshore wind development within the nearshore region including military operations, height restrictions around Diu airport, environmental sensitivity and fisheries. It is therefore recommended to focus efforts on pursuing the development of offshore wind beyond the 12 nautical mile boundary, in the zones identified with high potential, numbered 1 to 5 in this report. These zones could potentially accommodate approximately 11.8 GW of installed wind power capacity, based on an assumed density of 5 MW per km².

2. Allocate space at sea for offshore wind legally through a political agreement

As well as being the only suitable area for offshore wind development, the offshore region south of Gujarat is a highly productive oil and gas basin with a large number of active and prospective fields. It is recommended to reserve the remaining favourable offshore wind development sites and allocate the sea space for wind energy, ensuring that the limited available resource is used effectively.

The government is encouraged to set the direction and be clear about its priorities in balancing economic growth, social inclusion and environmental sustainability.

For developers of offshore wind projects, the certainty on political, regulatory and consenting conditions are key elements to evaluate associated risk to the business case, and their interest into entering a bid process for a site.

3. Prioritise efforts, starting with the best sites

The identified zones have a varying level of favourability, ranked in section 6, which indicates the likely relative Levelized Cost of Electricity. When investigating further, it is recommended to prioritise development of these areas starting for the lowest likely cost. This approach will encourage faster build-out of the first offshore wind farms and allow the supply chain and infrastructure to mature as more projects are tendered.

4. Stakeholder engagement

Marine Spatial Planning forms the basis of allocating sea areas for various use cases. In addition to data collection and mapping, it requires stakeholder engagement to ensure consensus, mitigate risks and progress with development at the desired pace. This will require coordination negotiation between authorities, for which a designated authority should be appointed.

It is recommended that authorities engage at this early phase with stakeholders related to the various topics included in this study. Public hearings are often used to invite input and feedback from a broad range of stakeholders.

5. Site investigations

Preliminary site investigations are essential in the early phase of offshore wind development. This limits risk to the realisation of the project through providing information on the seabed, metocean conditions and environmental impacts, allowing for appropriate design and timely mitigation strategies. Seabed, metocean and environmental surveys have been conducted for the VGF site B, further surveys will be required for the proposed development zones once they have been selected for tender.

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WSP 2024. Environmental note - crane and birds of prey avoidance response to offshore wind farms

Appendix A. Coordinates of proposed OSW development zones

The coordinates of the proposed offshore and nearshore development zones used in this study are given in the following table.

Zone	Longitude (deg)	Latitude (deg)
1	71.57779333	20.49503969
1	71.48027045	20.42633834
1	71.17192124	20.51335614
1	71.5260791	20.72803488
2	71.78784656	20.56022693
2	71.62059126	20.52265224
2	71.5969546	20.62937602
2	71.60274951	20.63243454
2	71.78637739	20.72915695
3	71.78972928	20.33832847
3	71.65269034	20.37738594
3	71.63036294	20.4784705
3	71.78824371	20.51393817
4	71.4539872	20.19328775
4	70.9224169	20.35809148
4	71.09994033	20.46748024
5	71.61165491	20.34193841
5	71.66828886	20.0849226
5	71.17984545	20.46407052
6	71.36577881	20.68288709
6	71.16543881	20.56429502
6	70.85917191	20.65870813
6	71.13435157	20.71167157
6	71.37038433	20.82335537
7	71.64617646	20.82784103
7	71.60086839	20.89754576
7	71.85006282	21.04218309
7	71.88230126	20.9768349

Table - A.1 Coordinates of proposed offshore wind development zones

Appendix B. Producing a weighted heat map using QGIS

A heat map is a data visualization technique that shows the magnitude of a metric through colour. This section explains how to create such a map using the open-source software QGIS (<https://qgis.org/>). The map is typically produced using one or multiple raster layers. When multiple metrics e.g. wind speed and water depth need to be visualized in one layer, the values are reclassified from actual values (e.g. wind speed in m/s) to dimensionless values (e.g. 1-100). This reclassification of the data enables the summation of two or more metrics.

In this case, the areas with the highest wind speed and the lowest water depth are visualised in order to determine the most suitable areas for offshore wind development. The spatial information on wind speed (m/s) and water depth (m) must be combined by assigning dimensionless values by using the raster analysis tool: reclassify by table. Then the reclassified data are combined using the raster calculator tool.

B.1. Reclassify the wind speed and bathymetry data

To reclassify the data into intervals in order to nondimensionalise the metric, open the processing toolbox in the user panel and search 'reclassify', see figure 1.5.

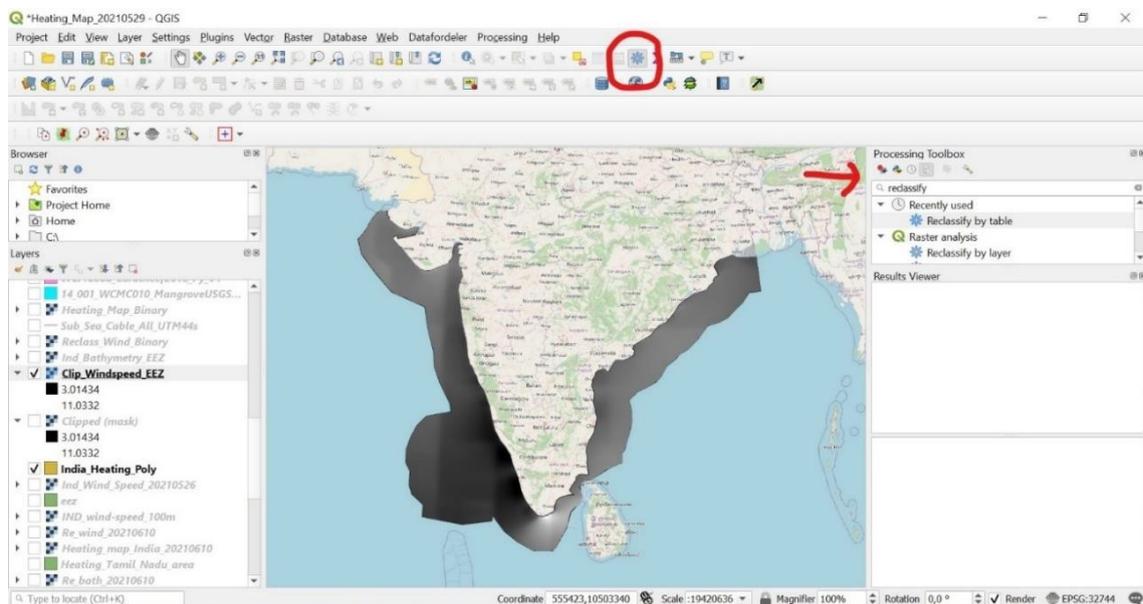


Figure B.1.1. - Clipped wind speed raster and processing toolbox

Click on reclassify by table and input relevant information. Choose your clipped raster layer as raster layer and check the box: Use 'no data when no range matches value' and save the output file, see figure 1.5.

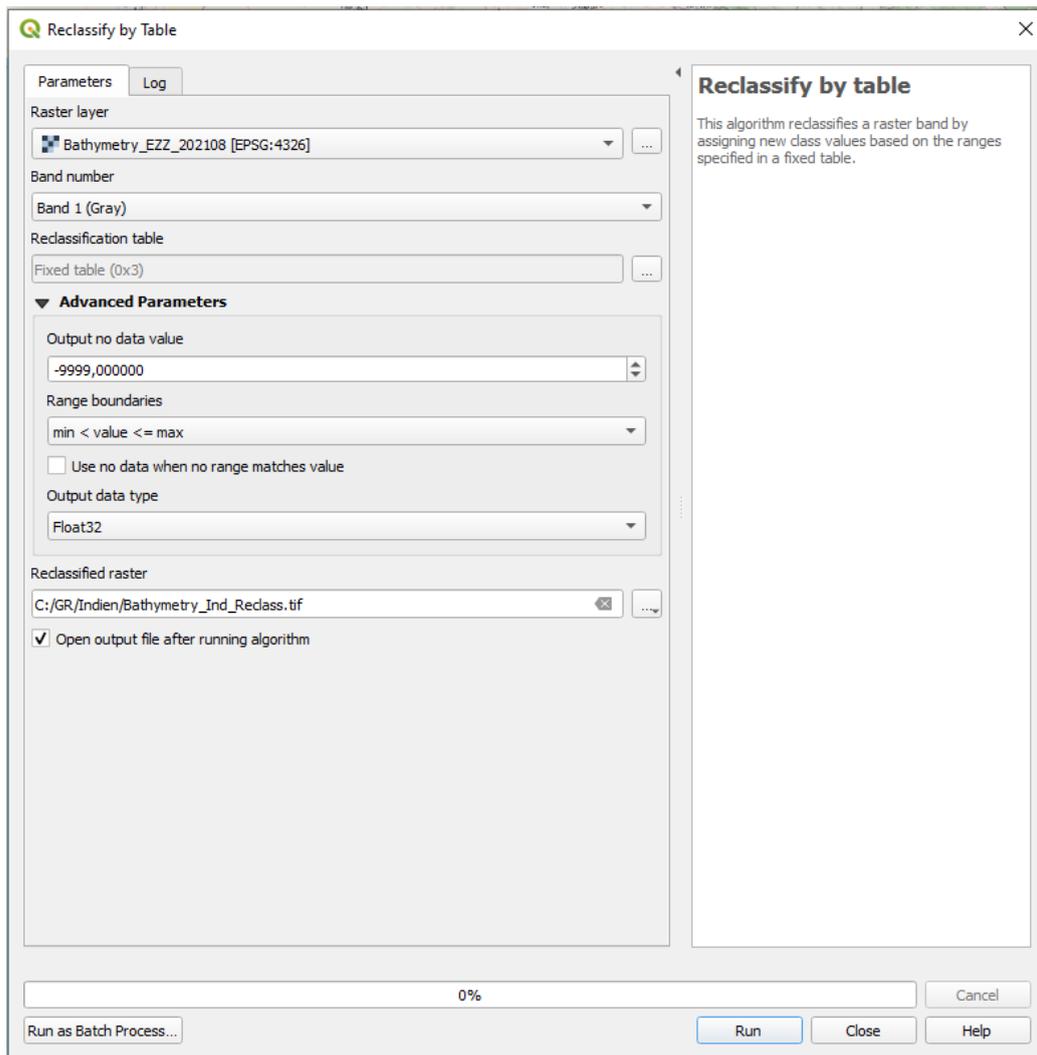


Figure B.1.2. - Reclassify by table

Before clicking run, define the reclassification table. Click  in order to open the **reclassification table** and add rows and insert the desired intervals.

In this example, the bathymetry data is classified into eight categories with a minimum water depth of -50 m and the maximum water depth of -10 m. Each water depth interval is assigned with a value from 1 to 8. With 1 being the least favourable water depth and 8 the most suitable water depth, following the principle that shallower waters require lighter and therefore cheaper foundations. Water shallower than 10m depth can be challenging to access with conventional offshore installation vessels, and therefore are not given a favourable ranking. The input values are shown in table 1.

The wind speed data is also divided into 8 categories. The preferred minimum wind is in this example set to 7 m/s and the maximum wind speed according to the wind dataset is 11 m/s. The

wind speed is considered more important economically when selecting a suitable offshore wind site and is therefore given a higher weighting. Instead of assigning values of 1-8, values of 2-16 are used. With 2 being the least favourable and 16 the most favourable wind speed. The input data is shown in table 1.

Minimum	Maximum	Value
-50	-45	1
-45	-40	2
-40	-35	3
-35	-30	4
-30	-25	5
-25	-20	6
-20	-15	7
-15	-10	8

Table B.1.1. - Input values for the reclassification table for bathymetry

Minimum	Maximum	Value
7	7.5	2
7.5	8	4
8	8.5	6
8.5	9	8
9	9.5	10
9.5	10	12
10	10.5	14
10.5	11	16

Table B.1.2. - Input data for the reclassification table

After the chosen rows and your values have been added, ensure to save the output file and click run. The reclassified raster should look similar to figure B.1.3. and figure B.1.4.

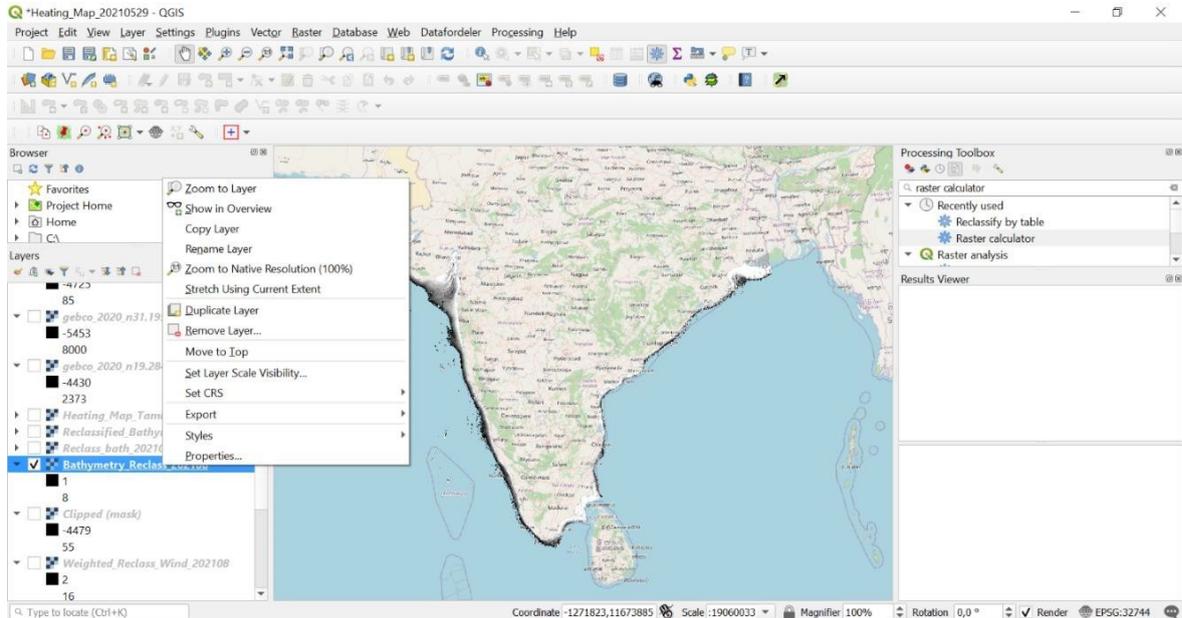


Figure B.1.3. - Example of reclassified bathymetry raster layer

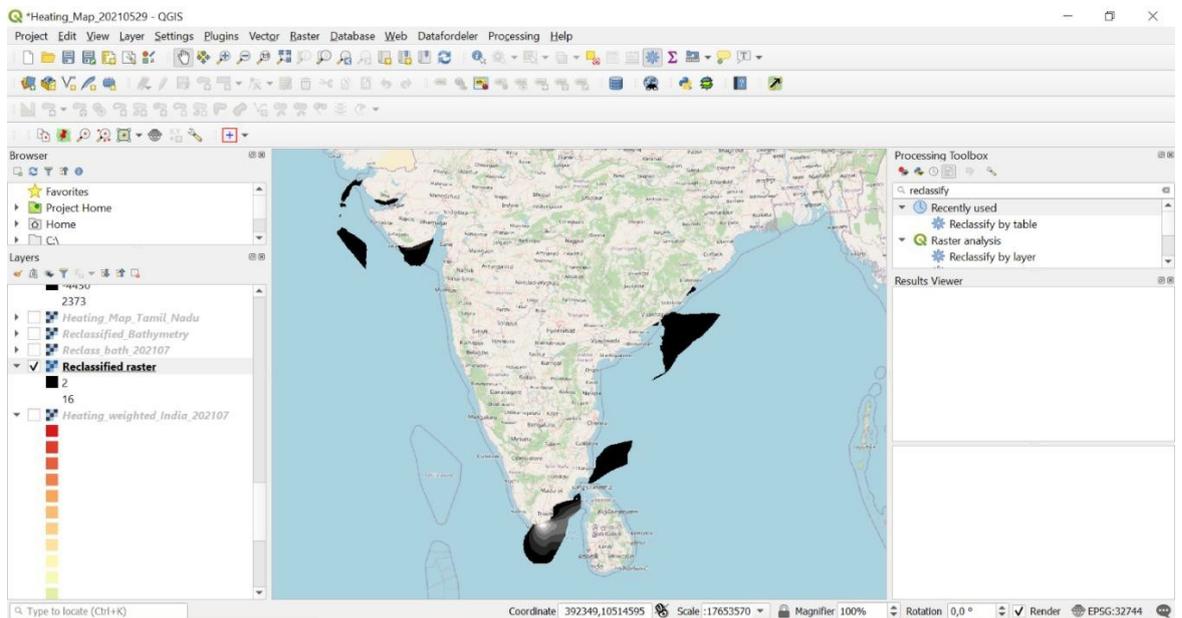


Figure B.1.4. - Example of reclassified wind speed layer.

B.2.Reclassify the wind speed and bathymetry data

The next step is to use the raster calculator to combine the reclassified values. When combining two raster layers, one layer will serve as the reference. Before starting, identify the pixel size of one of the two raster layers (bathymetry or wind speed). Right click on the clipped, reclassified bathymetry layer and open layer properties, see figure B.1.3. In the layer properties click on information in the left panel (Figure B.2.1.). Here, the pixel size of the bathymetry raster layer is 0.0042 and will be used in the raster calculator.

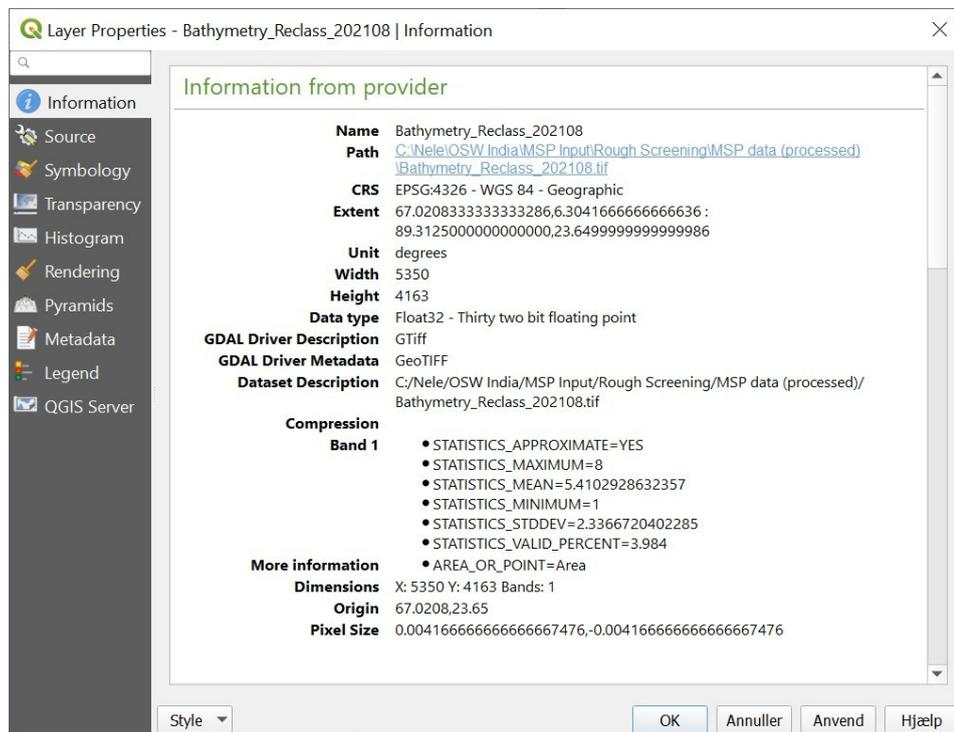


Figure B.2.1. – Layer Properties

Search for raster calculator in the processing toolbox and open it. In the raster calculator panel, add the relevant layers in the expression panel. Choose the weighted reclassified wind speed layer to make it visible in the expression panel. Before adding the bathymetry layer, choose the operator, in this case “+”. Then choose the reclassified bathymetry layer. The expression should be similar to the expression shown in Figure B.2.2.

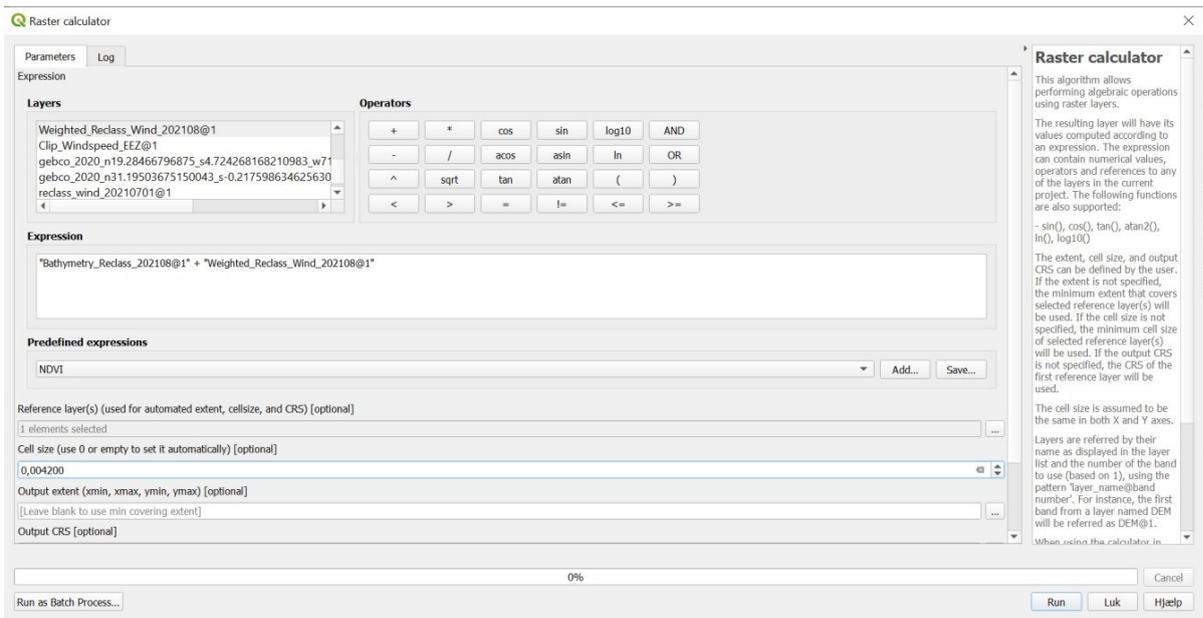


Figure B.2.2. - Raster Calculator Panel

Set the cell size to 0.0042 and save the output layer. Before clicking run, set the reference layer(s) to the classified bathymetry layer. See example in Figure B.2.3. Click ok, then run. The output is the final weighted heat map.

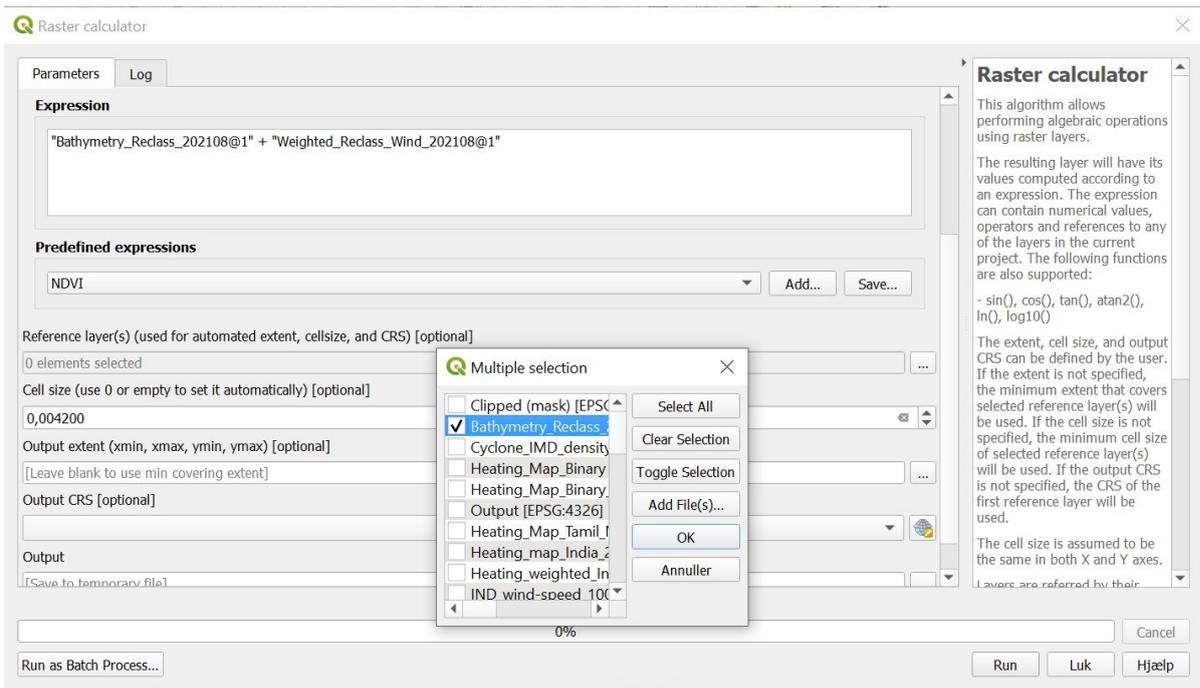


Figure B.2.3. - Raster Calculator Panel

B.3. Classify the result

The resultant heat map visualizes the most suitable sites for offshore wind locations based on the two parameters chosen. The last step is now to visualize the data correctly. Open the properties layer by right clicking on the weighted heat layer. In the left panel click on symbology. Set the render type to single band pseudocolour. Set the mode to equal interval and set classes to 21. Chose a colour ramp and click ok, see figure B.3.1.

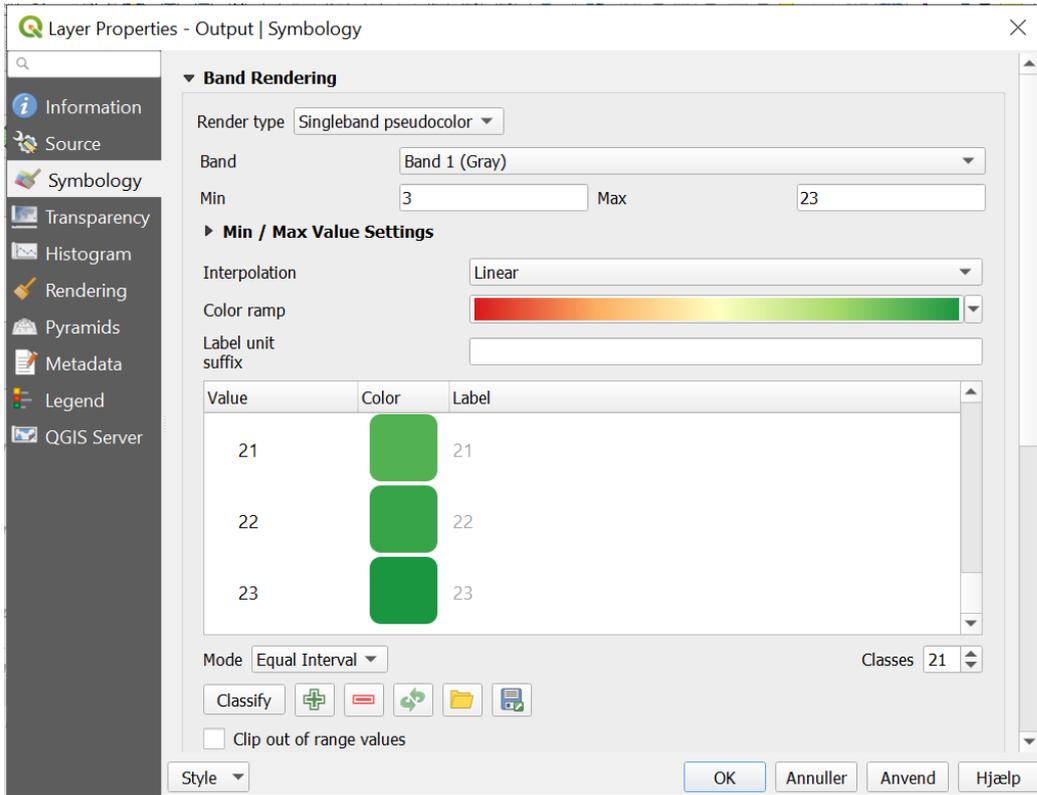


Figure B.3.1 - Layer Properties Symbology

The resulting heat map should look similar to the one shown in figure B.3.2. where green indicates the most favourable sites.

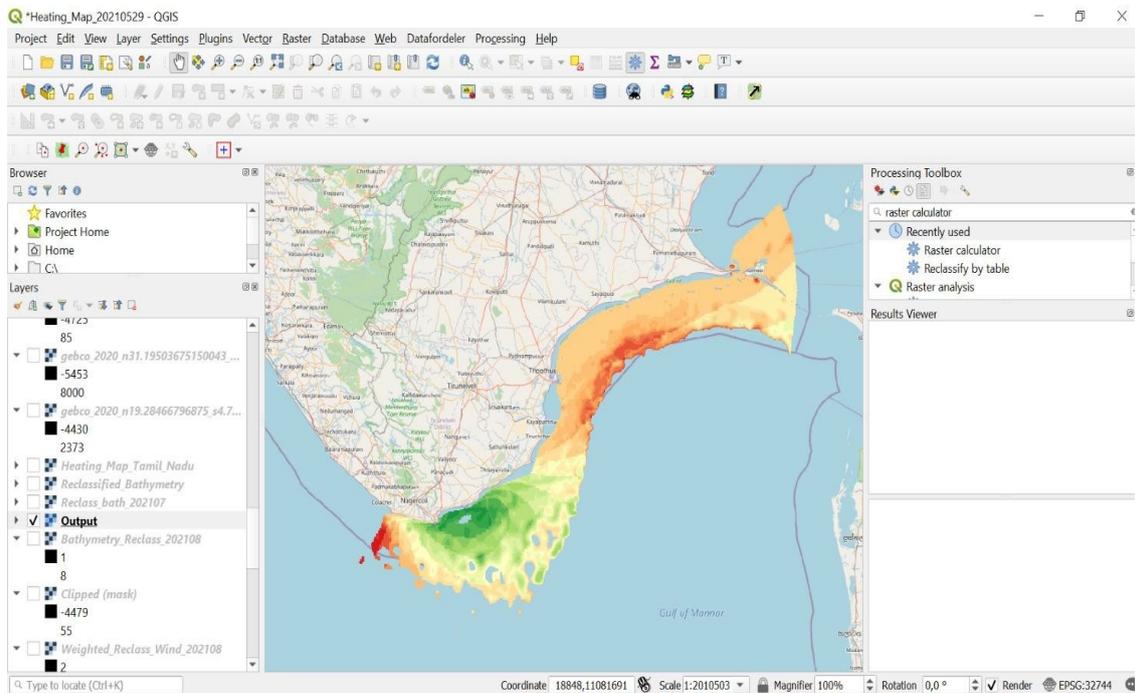


Figure B.3.2. - Final heat map showing India

B.4. Ranking zones in order of favourability

Once polygons have been drawn to represent potential offshore wind development sites, it is possible to extract the values from the heat map layer in order to rank them according to their favourability.

Search for 'Zonal statistics' the Processing Toolbox to open the dialogue box shown in figure B.4.1. This algorithm calculates statistics of a raster layer for the features of a polygon vector layer. Select the relevant input layer with the offshore wind site polygons, and the raster layer with the heat map values. In the field 'statistics to calculate', the default includes mean which will give the mean value for the heat map within the boundaries of each site. It is also possible to add more statistics, such as maximum and minimum. After running the algorithm, a new layer is calculated with the requested statistics shown in the attribute table for each feature.

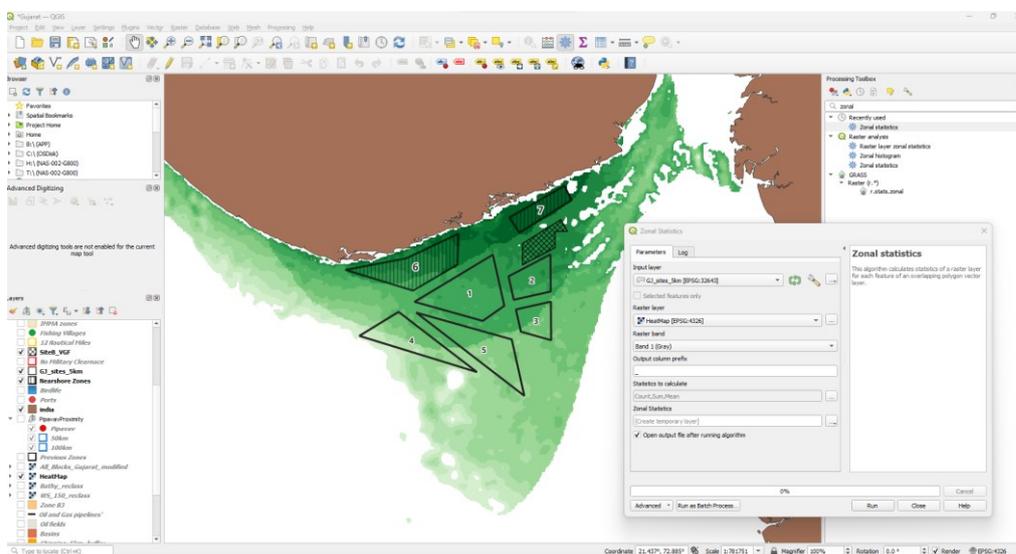


Figure B.4.1. - Calculation of heat map ranking for offshore wind zones