Maritime Spatial Planning for offshore wind farms in Gujarat

24 February 2023

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for Offshore Wind and Renewable Energy

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This document is intended to serve as an explanation of the maritime spatial planning methodology and process in an Indian context with a focus on offshore wind. This report was jointly prepared by the Danish Energy Agency (DEA) and COWI after consultations with Ministry of New and Renewable Energy (MNRE) and the National Institute Wind Energy (NIWE). The assumptions and opinions expressed in this report do not necessarily reflect the view of the Government of India and its related agencies on offshore wind development and/or policies. The document is primarily for use within the bilateral energy partnerships. The document has been written and proof-read by a group of DEA employees with different backgrounds, perspectives of and experiences within the offshore wind sector. We have in certain places offered opinions and views of best practice that may not necessarily be true in all cases. We have to a limited degree offered views on where the future development might be leading, which may not necessarily end up being the case. In spite of that risk we thought it would add value to the narrative. In spite of our best efforts to be correct in all aspects of the narrative, the document may contain errors. This document does not have any legal status and is not an official and legally binding DEA document.

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Authors

Alp Gunsever, Head of Secretariat, Centre of Excellence for Offshore Wind and Renewable Energy, lpgn.coe@gmail.com

Matthew Delany, Chief Advisor, Danish Energy Agency, mhdl@ens.dk

Contributors

Dr Prabir Kumar Dash, Scientist-D, Head of Wind Energy Division, Ministry of New and Renewable Energy, prabir.dash@nic.in

Dr Rahul Rawat, Scientist-C, Ministry of New and Renewable Energy, rahul.mnre@gov.in

Rishikesh Vasihnav, Scientist-B, Ministry of New and Renewable Energy, rishikesh.mnre@gov.in

Sarreen Sara Solomon, Young Professional, Ministry of New and Renewable Energy, sarreen.sara@nic.in

Dr Rajesh Katyal, Director General (Additional Charge), National Institute of Wind Energy, katyal@niwe.res.in

Dr K. Boopathi, Director & Division Head, National Institute of Wind Energy, boopathi@niwe.res.in

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Abbreviations

AIS	Automatic Identification System
ATS	Air Traffic Control
CoE	Centre of Excellence for Offshore Wind and Renewable Energy
CTV	Crew Transfer Vessel
DGH	Director General of Hydrocarbons, Government of India
DST	Department of Science and Technology
DTU	Danish Technical University
EBSA	Ecologically or Biologically Significant Marine Areas
EMODnet	European Marine Observation and Data Network
ESIA	Environment and Social Impact Assessment
GIS	Geographical Information System
GSHAP	Global Seismic Hazard Assessment Program
GSI	Geological Survey of India
GW	Giga Watts
GWA	Global Wind Atlas
HVDC	High Voltage Direct Current
IBA	Important Bird Areas
IMD	Indian Meteorological Department
IMF	International Monetary Fund
IMMA	Important Marine Mammal Areas
IMO	International Maritime Organisation
IRA	Internationally Recognized Areas
IUCN	International Union for Conservation of Nature
kV	Kilo Volts
LCoE	Levelized Cost of Electricity
LPA	Legally Protected Areas
MNRE	Ministry of New and Renewable Energy
MoD	Ministry of Defence, Government of India
MOEF&CC	Ministry of Environment, Forest and Climate Change
MoES	Ministry of Earth Sciences
MoPSW	Ministry of Ports, Shipping and Waterways
MSP	Marine Spatial Planning
MWh	Mega Watt hours
NCCR	National Centre for Coastal Research
NIWE	National Institute of Wind Energy
NOC	No Objection Certificate
O&G	Oil and Gas
O&M	Operation and Maintenance
OHL	Overhead Line

OnSS	Onshore Substation
OSS	Offshore Substation
OWF	Offshore wind farm
PGCIL	Power Grid Corporation of India
POC	Point of Connection
T&I	Transportation and Installation
TBC	The Biodiversity Consultants
TRANEDCO	Tamil Nadu Generation and Distribution Corporation Limited
TSO	Transmission System Operator
TSS	Traffic Separation Scheme
UNCLOS	United Nation Laws of the Sea
UXO	Unexploded ordnance
WTG	Wind Turbine Generator

Executive summary

This report 'Maritime Spatial Planning for Offshore Wind Farms in Gujarat' focuses on the Gujarat offshore wind potential and presents the importance of marine spatial planning in building up a pipeline of projects. Besides describing the screening methodology, the report presents the outcome of the rough and fine screening process including the heat mapping and conceptual planning basis for the selected zones off the coast of Gujarat for further stakeholder consultations and inputs. The report will further provide a specification of the focus areas for development of offshore wind farms.

While the exercise of carrying out maritime spatial planning is a continuous process, this report is prepared to present the current status and outcome of rough and fine screening and further technical analysis conducted to identify most suitable areas for priority offshore wind farm development, considering various physical, environmental, and social parameters.

The analysis conducted has identified oil and gas activities as a key constraint and significant competing users within the OWF Zone in Gujarat. At this stage there are as expected a number of other constraints and risks that needs to be further analysed as part of the on-going discussions of co-existence with competing users.

As part of the maritime planning exercise, an analysis of the indexed Levelized Cost of Electricity (LCoE) has also been carried out, and the results are illustrated as so-called heat maps.

As for the report focused on the 'Maritime Spatial Planning for Offshore Wind Farms in Tamil Nadu' (CoE, 2022) a further technical analysis was carried out to formulate the basis for conceptual planning of the relevant sites, including those related to:

- Energy (turbine) density to be adopted for planning purposes, based on experience from countries such as Denmark, UK and Germany;
- Module size consideration, considering electrical power system as a limiting factor for individual wind farms within the shortlisted sites;
- Seabed screening based on available data in public domain;
- Turbine suitability;
- External wake loss and separation distance between the plots;
- Electrical power systems and export configuration; and
- Port and logistic infrastructure.

The above considerations provided inputs to a preliminary conceptual plan and are prepared for consultation with Indian Stakeholders and alignment on the planning principles.

The specific data and information gathered via the various surveys and investigations together with the relevant studies and assessments for the zone B3 carried out by NIWE is of course extremely important as part of the de-risking and further development of offshore wind. Following the focus on zone B3 as the first part of the build-out plan it is of course important to take into account the assessments and considerations made during rough and fine screening, the heat mapping and conceptual planning. Bearing these in mind the most attractive parts off the Gujarat coast would be to the West for the zone B3 into the zone A. These zones represent the best sites from a LCoE perspective.

Considering the water depths in particular the zone D and parts of zone E and F are within areas with deep water above 65 meter, which means that most of zone D and parts of zones E and F are not assessed to be suitable for fixed-bottom offshore wind turbines.

Especially the constraints related to the oil and gas activities seems challenging to the eastern and southern parts of the zones off the coast of Gujarat – both considering actual oil and gas fields, but also the active and awarded oil and gas blocks, which are overlaying with especially the zones B, E, D and F.

Considering the Ministry of Defence (MoD) only the following zones: A, B, D, E and F have been given in-principle clearance by MoD based on previous communication, and it will of course be important to maintain communication with MoD.

Considering the environmental aspects and sensitive areas the zones C, G and H are the most constrained. The fact that the Ministry of Defence has not given in-principle clearance for these zones, and the relatively less attractive LCoE level categorizes the zones G and H as the least suitable zones for development of offshore wind farms.

Subject to the feedback from the Ministry of Defence it would be relevant to also consider the suitability of the corridor in between zone A and zone C for offshore wind farm development. This corridor if added to zone A can increase the capacity to be allocated in the region. Within this combined area there will remain a number of constraints, and as described the marine traffic in particular would need to be considered and as indicated the previous allocated corridors could potentially benefit from being reassessed to optimize the co-existence between marine traffic and offshore wind. Many other constraints and risks will need to be assessed further and the actual division into specific module size areas and providing areas for the electrical infrastructure will also impact the actual area available for the deployment of offshore wind turbines.

Based on this Maritime Spatial Planning report the spatial conflicts amongst various stakeholders are identified to further discuss mutual coexistence of the various interest groups. To attain the objective of the maritime spatial planning, it is extremely important to conduct consultations with relevant stakeholders, and it is highly recommended that focused consultations are carried out with various parties for de-conflicting the offshore wind farm development and obtain continuous and regular feedback on planning proposals for realignment and refinement of proposed development plans.

1. Introduction

India and Denmark are 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 in the Indian context. The cooperation on offshore wind energy has developed gradually in dialogue with the Indian counterparts. The overall objective is to support Ministry of New and Renewable Energy (MNRE) in their work for the implementation of 30 GW offshore wind by 2030.

The main objective of the current assignment is to notify 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 30 GW offshore wind by 2030. The most suitable zones and project sites for deployment of offshore wind will be identified via maritime spatial planning including a rough and fine screening.

This report focuses on Gujarat and presents the importance of marine spatial planning in building up a pipeline of projects. Besides describing the screening methodology, the report presents conceptual layouts of the selected zones off the coast of Gujarat for further stakeholder consultations and inputs.

1.1 Objectives & Scope

The objectives of this report are:

1) To describe the methodologies used for assessing and ranking potential offshore wind sites, in order to provide capacity building to the NIWE and other Indian stakeholders on maritime spatial planning including rough and fine screening.
2) To improve the decision base 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 and prepare the initial build-out plan of offshore wind project within the identified wind zones of Gujarat to support the overall target of 30 GW by 2030.

2. Marine Spatial Planning (MSP)

A general introduction to MSP has been given in the MSP report for Tamil Nadu (CoE, 2022). Please refer to that report for this general introduction.

2.1 Methodology

The same methodology explained in the MSP report for Tamil Nadu is implemented here in this report for Gujarat (CoE, 2022). The biggest difference is in the depth of the analysis which is caused by the total capacity allocated until 2030. According to the auction trajectory in the strategy paper, an initial total capacity of 1 GW is planned for offshore wind development in India, which means that economic ranking of sites, buildout plan for the whole area and considerations for external losses will not be performed to the same level as for Tamil Nadu. Nevertheless, the aim is still to ensure the best possible use of the marine space in an efficient, safe and sustainable way.

2.2 Rough Screening

Rough screening is carried out considering primarily the wind speed (above 7 m/s) and water depths (between 10-65 meters) to identify the economically most viable areas for offshore wind development in Gujarat. Figure 2.1 below provides a heat map of India which illustrates the wind speed and water depths in the offshore areas of Gujarat and within the zones identified for development of offshore wind farms.

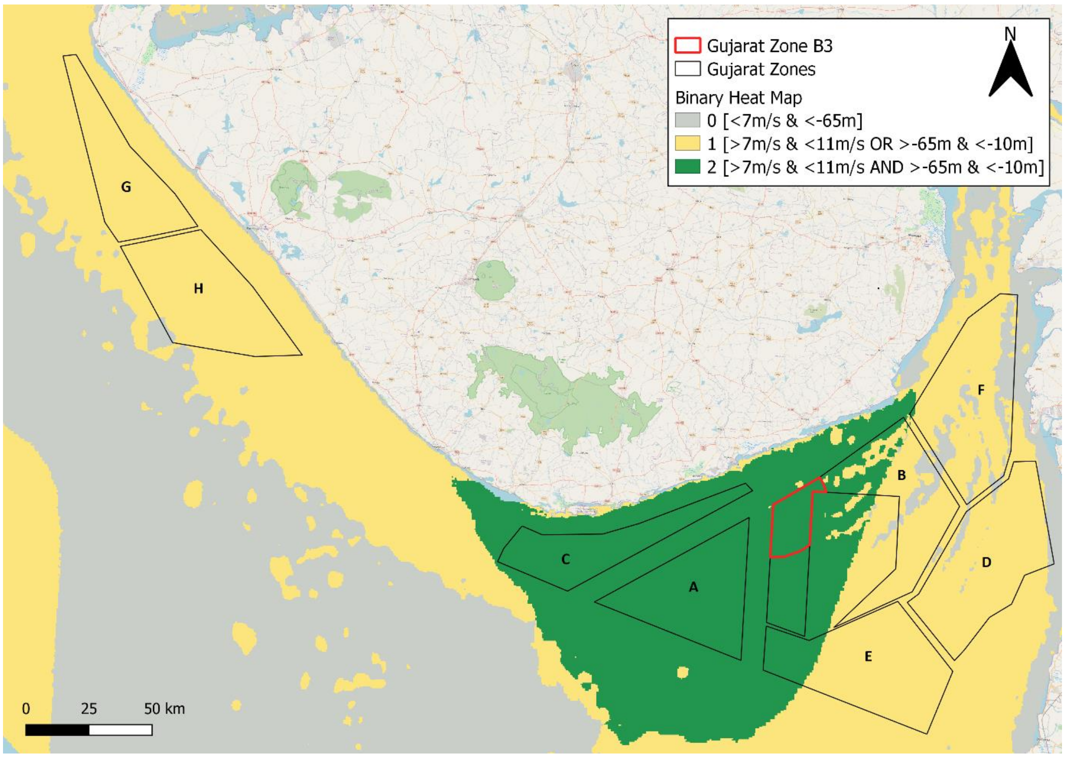

Figure 2.1 - Binary heat map of Gujarat

As can be observed from the heat map, the areas off the coast and within zone A, B, C and partially zone E and F are ideally suited from the perspective of both wind speed and water depths, providing an optimum wind resource (> 7m/s) with water depths of -10 to -65m, which is considered to be best suited for development of offshore wind farms in Gujarat. However, the areas in zone G, H and D are seen to have a wind speed of less than 7m/s with water depths of -10 to -65m, which could be less suited as compared to the other zones described above.

2.2.1 Wind Climate

The wind speed data for rough screening, imported from the Global Wind Atlas as wind speed 150 m above sea level depicts that wind speeds reaches up to 8.5 m/s and wind speeds above 8 m/s are particularly seen to be concentrated in the southern offshore regions near zone A, C and parts of zone B.

Wind speeds in zones A, B and C varies from 7 to 8.5m/s, however at zone G, H, D and parts of zone E and F the wind speeds are observed to be less than 7m/s (see Figure 2.2). It should be noted that seasonal changes in wind direction and magnitude have not been taken into consideration in this rough screening exercise.

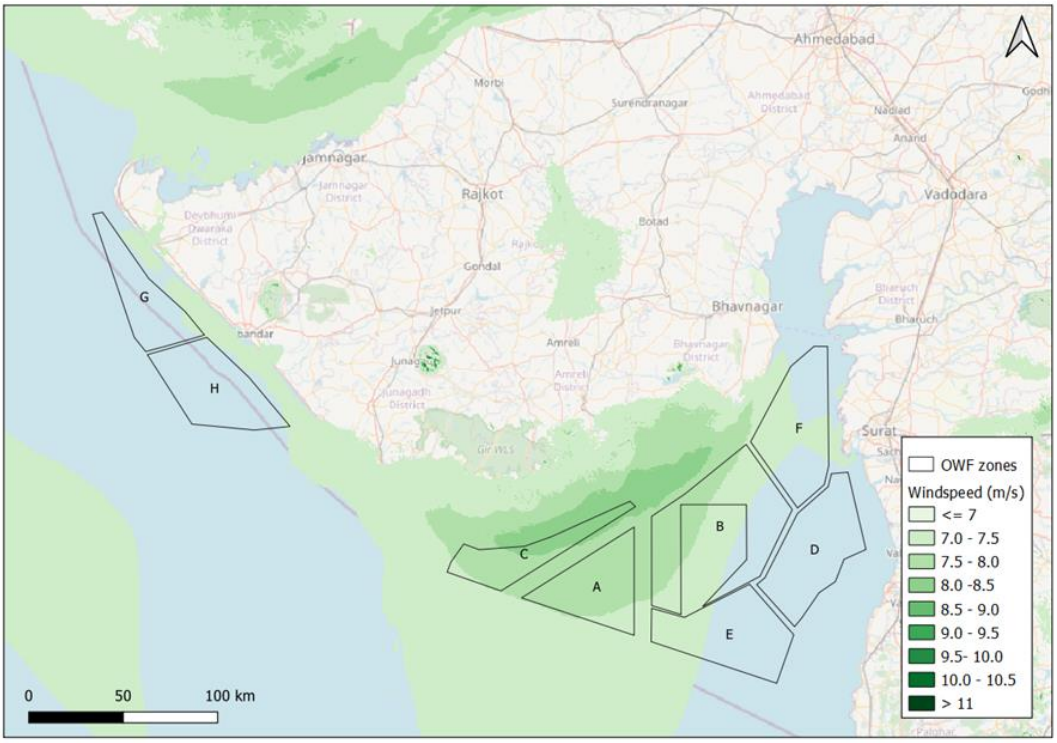

Figure 2.2 - Windspeed map of Gujarat with speeds >7m/s, showing the OWF zones (ESMAP, 2022)

2.2.2 Seabed Conditions

The rough screening considered bathymetry, water depth and seismic risks as the only parameters in relation to foundation conditions and costs from the seabed conditions perspective. Figure 2.3 exemplifies water depths in the west coast of India, near and offshore areas ≥-50 m and ≤-10 m and it is observed the OWF zones in Gujarat exhibits few areas of water depth greater than 50 m. The distant areas of zone G and H are however seen to have depths slightly deeper than -50m.

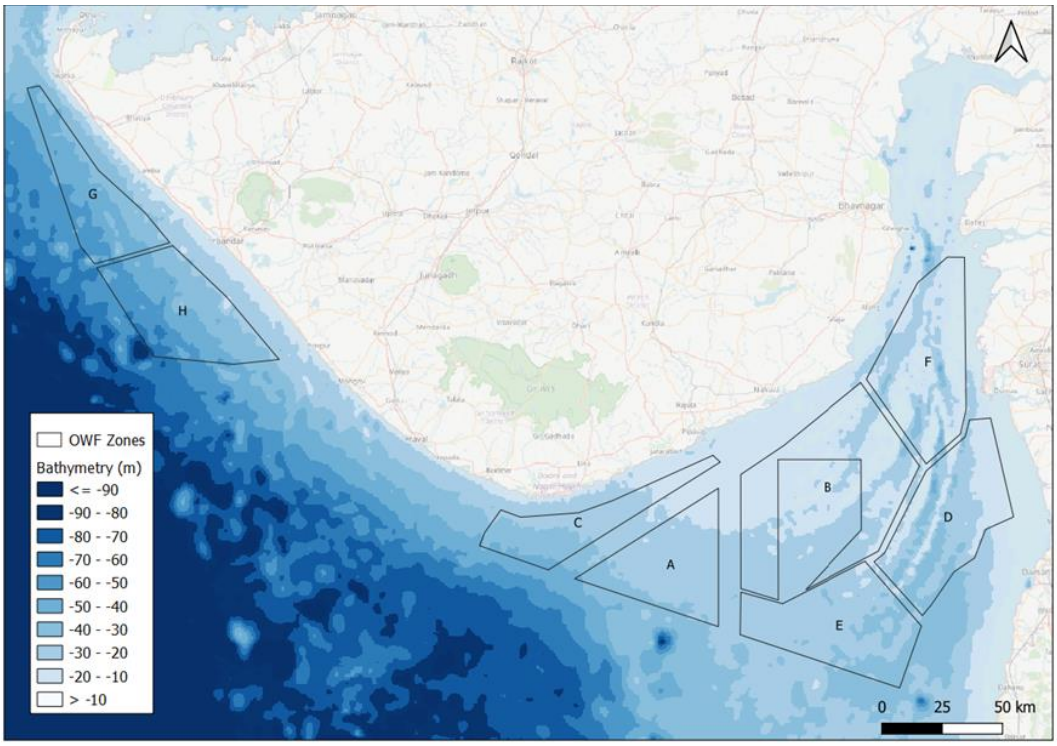

Figure 2.3- Bathymetry map of Gujarat showing the Offshore Windfarm zones (ESMAP, 2022)

2.2.3 Environmental Considerations

Environmental constraint mapping is considered during the rough screening to identify the real potential(s) for offshore wind development and to avoid adverse impacts on biodiversity of the area under consideration.

The information presented in this section is based on the initial report and Geographic information system (GIS) files received from The Biodiversity Consultants (TBC) commissioned by the World Bank Group to provide information on the key biodiversity areas. Additionally, COWI's own research and database has been used for collating and presenting information on birds and avifauna. The study focused on identification and mapping on the following key groups of priority biodiversity values:

- Legally Protected Areas (LPAs) and Internationally Recognized Areas (IRAs);
- Marine mammals;
- Birds;
- Fishes; and
- Natural habitats.

Based on the information presented, exclusion and restriction zones have been identified, which formed the basis for further consideration during the sustainable conceptual planning of the selected zones.

2.2.3.1 Legally Protected Areas

Legally Protected Areas (LPAs) and Internationally Recognized Areas (IRAs) represent high value areas designated for various biodiversity conservation objectives. This may include marine national parks, nature reserves, sanctuaries, Ramsar sites, Key Biodiversity Areas including Important Bird Areas (IBA's), Ecologically or Biologically Significant Marine Areas (EBSA's) and Important Marine Mammal Areas (IMMA's).

The Gulf of Kutch Marine National Park located in the northwest of Gujarat is one of the designated marine national parks of the country where no human activity is permitted, except those permitted by Chief Wildlife Warden for activities such as ecotourism.

The Khijadia bird sanctuary and Gulf of Kutch sanctuary are also designated wildlife sanctuaries in Gujarat.

Figure 2.4 provides an overview of the KBA’s and LPA's in Gujarat.

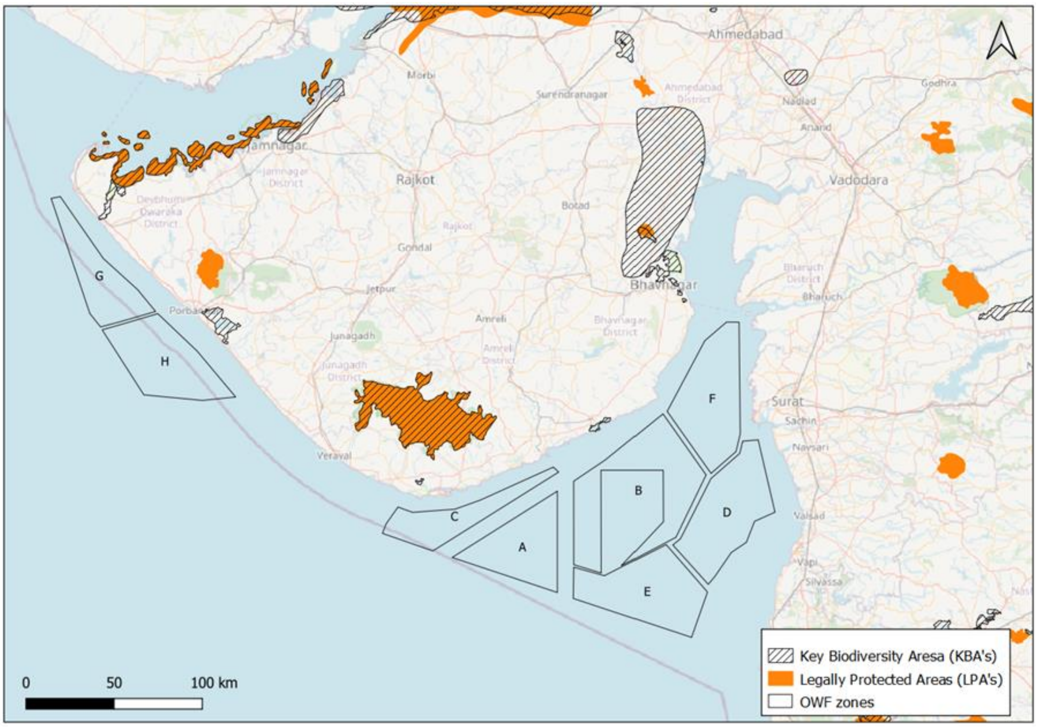

Figure 2.4 - Legally Protected Areas around OWF zones (COWI, 2022)

2.2.3.2 Marine Mammals and Turtles

The Gulf of Kutch IMMA (Important Marine Mammal Areas) in Gujarat is an important area for small Dugong population, which depends on large seagrass meadows in the gulf (Marine Mammal Protected Areas Task Force, 2021).

The Indus estuary and creeks IMMA is also important for Indo pacific Finless Porpoise and the Indian Ocean humpback dolphin, of which only the southern portion falls within Gujarat.

The Northeast Arabian Sea IMMA which extends from Central and north Gujarat, is well known for Blue whales and also supports a wide range of cetacean diversity.

Figure 2.5 illustrates the key habitats for marine mammals and turtles around the OWF zones. The mapped area includes turtle nesting sites (including 5 km buffer), Dugong habitat (including 25 km buffer) and International Union for Conservation of Nature (IUCN) designated IMMA's.

It can be observed from Figure 2.5, that zones G and H and a minor part of zone C are overlapping with the IMMA's, which are to be considered as restriction zones for development of offshore windfarms.

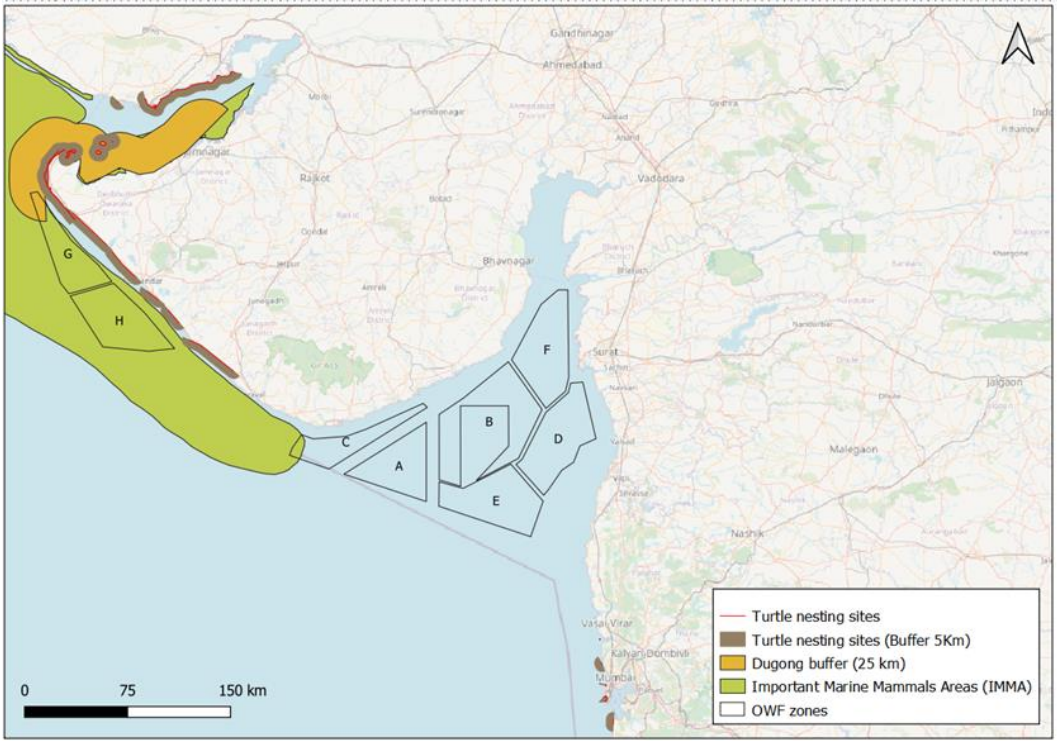

Figure 2.5 - Habitats and buffer zone for marine mammals and turtles around OWF sites (COWI, 2022)

2.2.3.3 Birds

Birds' areas are considered as part of the designated LPA's and IRA's in India and specifically the identification of marine important bird areas including breeding colonies, foraging areas around breeding colonies, non-breeding concentrations, migratory routes and bottlenecks and feeding areas are crucial during the early development phase of the project.

Gujarat has eleven (11) Important Bird Areas (IBA's) of which seven (7) IBA's are observed to be located in close proximity of the offshore wind farm areas (BirdLife International, 2022).

These seven (7) IBA's include:

- Gulf of Kutch Marine National Park and Wildlife Sanctuary-Staging area for migratory birds and approx. 20,000 species of waterbirds, serves as breeding ground for Greater *Phoenicopterus ruber* and Lesser *P. minor* Flamingos, White Pelican (*Pelecanus onocrotalus*) and Avocet (*Recurvirostra avosetta*) in the country;

- The Gir National Park and Wildlife Sanctuary-Wetlands support several waterfowl species. Globally threatened species include Dalmatian Pelican *(Pelecanus crispus),* Greater Spotted Eagle *(Aquila clanga),* Indian Skimmer *(Rynchops albicollis),* Oriental White-backed Vulture *(Gyps bengalensis) and* Long-billed Vulture *(Gyps indicus);*

- Gosabara (Mokarsar wetland complex)-Waterbirds including black bellied tern and Dalmatian pelican can be found;

- Kaj Lake (Pipalava Bandharo)-Harbours more than 20,000 birds during winters including two (2) globally threatened species;

- Nikol Samadhiyala (Malan Wetlands complex)-Waterbirds including black tailed Godwit and Eurasian spoonbill;

- The Bhal area and Velavador National Park-Important breeding area for Lesser Florican, Sarus Crane and Harrier; and

- Saltpans of Bhavnagar-Wintering and staging area for waders, globally threatened species of Dalmatian Pelican (*Pelecanus crispus)* and migratory waterbirds.

Figure 2.6 below provides an overview of the Important Bird Areas (IBA's) in Gujarat, highlighting the ones located in near proximity of the OWF sites.

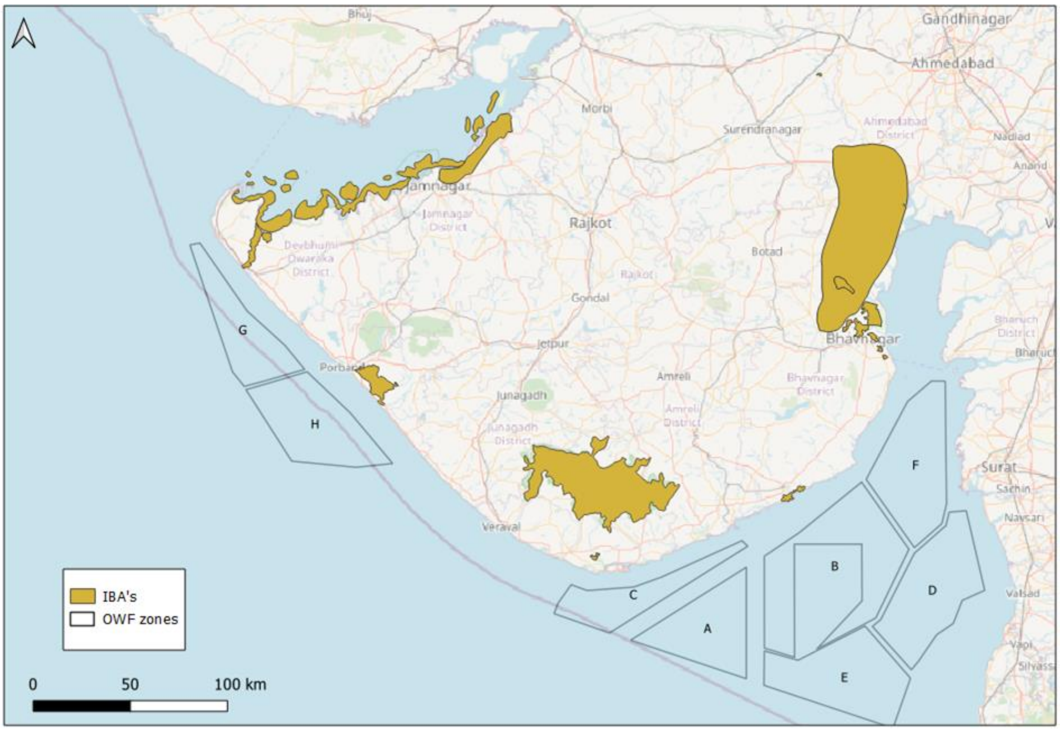

Figure 2.6 - Important Bird Areas (IBA's) in close proximity to OWF sites in Gujarat (COWI,2022)

It is however important to obtain further information to understand the migratory routes of birds in the area to include assessment of protected species and accordingly plan for mitigative measures.

2.2.3.4 Fish

At this stage limited digitized spatial data was found in relation to fish species and additional information will be required including assessment of protected species and the threat status.

Very few LPA and IRA designations include fish as specific features of interest, although many include habitats that are of likely importance to fish although many include habitats that are likely to be important for fish, such as seagrass meadows and mangroves.

2.2.3.5 Natural Habitats

Several marine ecosystems are highly important ecologically for the country. These includes seagrass beds, mangroves, coral reefs and coastal sand dunes. These biogenic habitats are therefore classified as restricted and no-go areas for offshore wind farm development including underwater cables and landfall locations.

2.2.3.6 Mangroves

Small areas of mangrove forests cannot be identified using the earth observation satellite imagery. Further uncertainties include cloud cover and noise as well as areas where land cover is misclassified. It is therefore suggested that a further assessment is conducted during the later phases of development through an Environmental Impact Assessment (EIA) study.

It can however be observed that large mangroves forest in the Gulf of Kutch constitute about 93% of Gujarat's mangroves, which is estimated to be around 5772 ha. (See Figure 2.7).

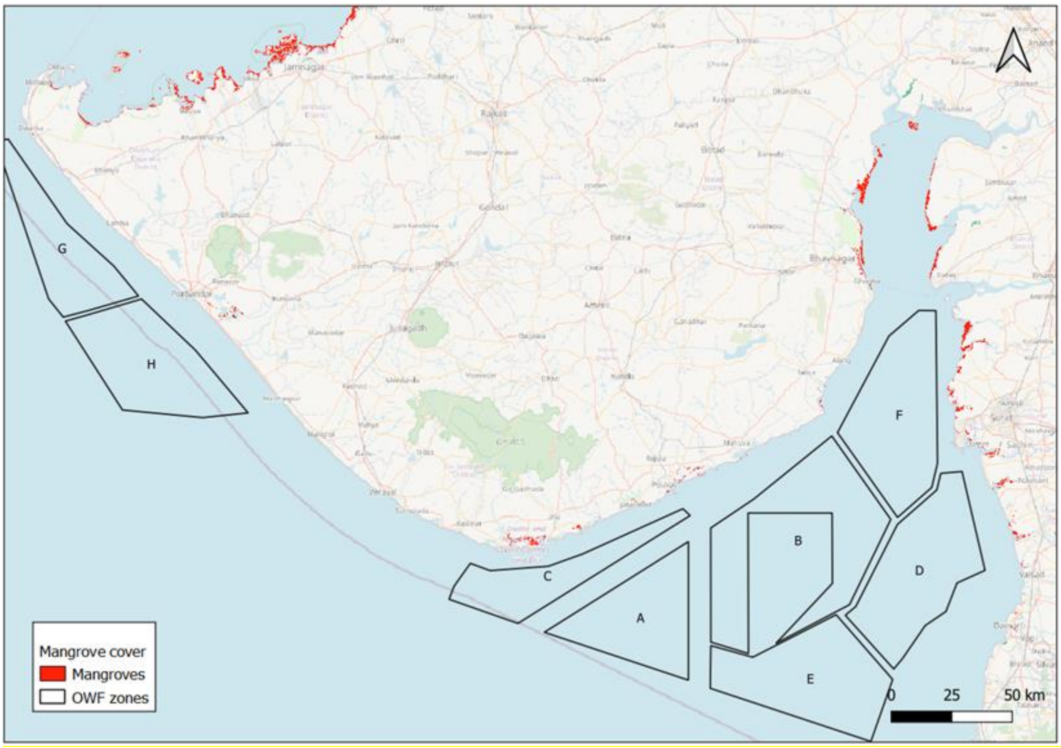

Figure 2.7 - Mangrove cover in Gujarat (COWI,2022)

2.2.3.7 Sea Grass and Coral Reefs

Six (6) species of seagrass are known to be found in the Gulf of Kutch, which are lately threatened by industrial pollution and climate change among many other factors. Seagrass also provides an important habitat for Dugongs.

Corals are seen to be distributed in patches in the Gulf of Kutch on sandstone substrate, which are also threatened due to natural and anthropogenic factors.

Figure 2.8 provides an overview of seagrass and coral distribution in Gujarat.

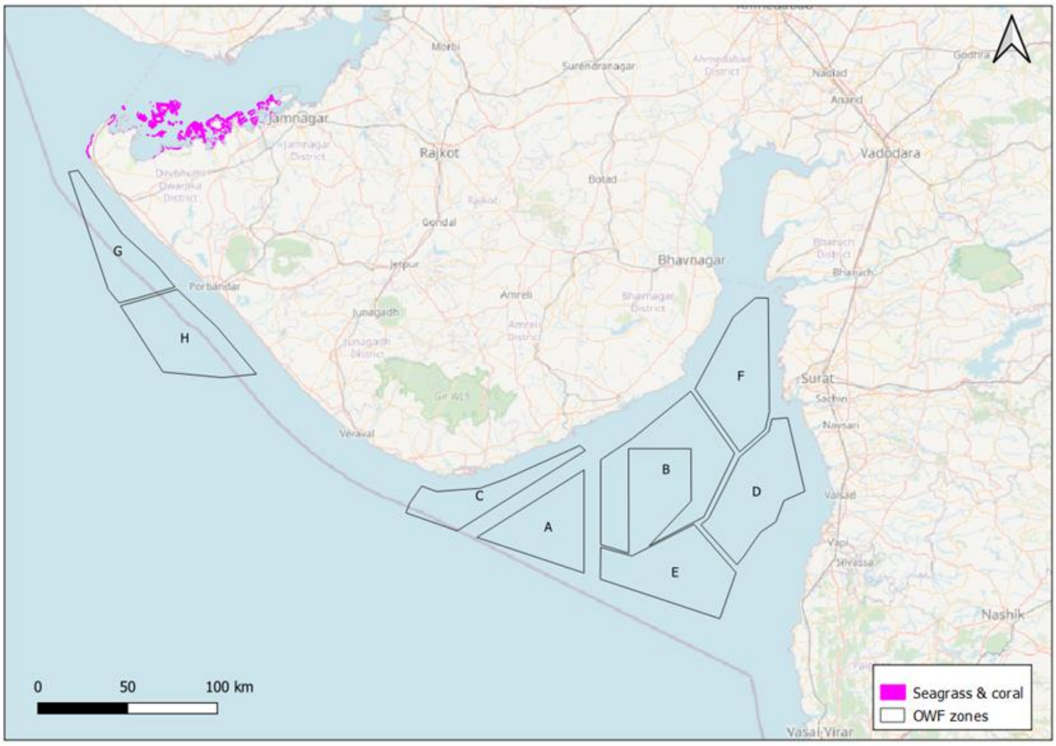

Figure 2.8 - Seagrass and warm water coral reef distribution in Gujarat (COWI, 2022)

2.2.3.8 Exclusion and Restriction Zones

Based on environmental constraint mapping (discussed above), exclusion and restriction zones have been identified. Exclusion zone refers to the areas of highest biodiversity sensitivity and needs to be excluded from further consideration of offshore wind farms and associated infrastructure (See Figure 2.9). Whereas Restriction zones are considered to be high-risk areas requiring further assessment during Environment and Social Impact Assessment (ESIA) should they conflict with the development planning for the OWF zones in Gujarat (See Figure 2.10).

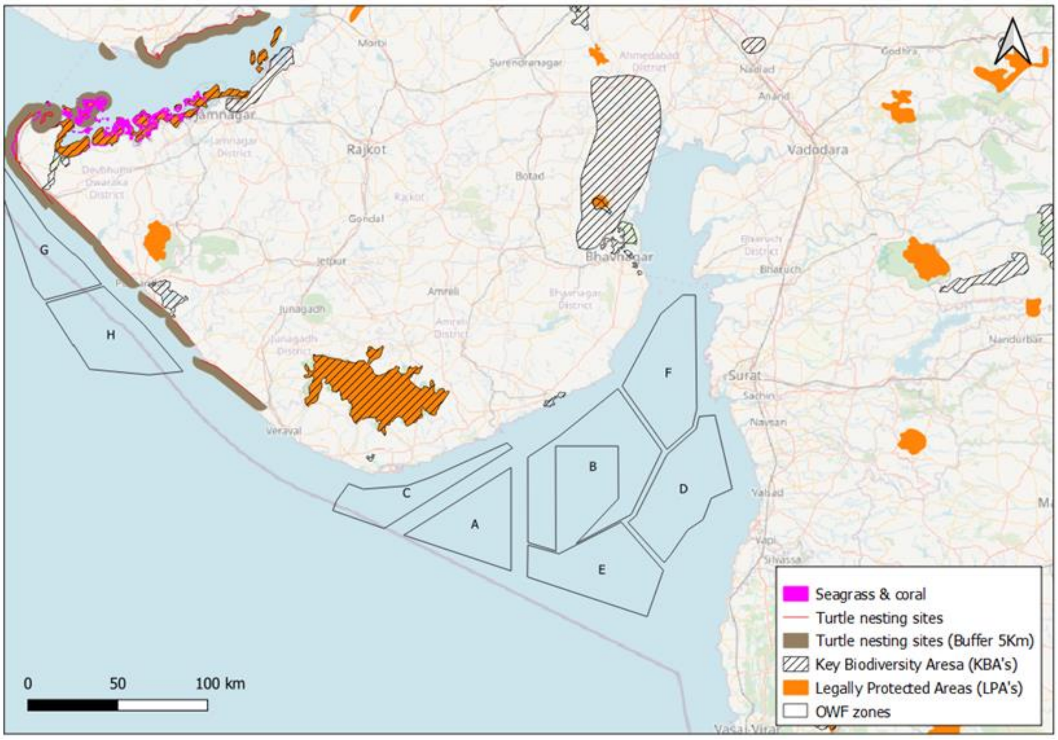

Figure 2.9 - Environmental constraint mapping -Exclusion zones around selected zones (COWI, 2022)

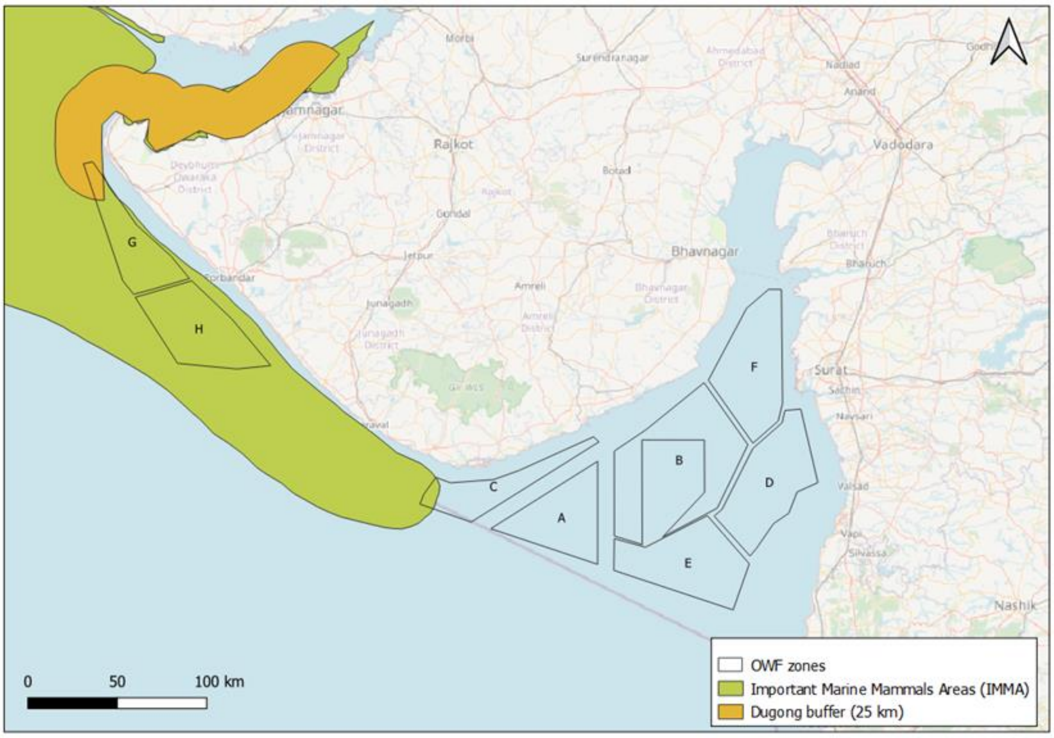

Figure 2.10 - Environmental constraint mapping -Restriction zones around selected zones (COWI, 2022)

Consider the different environmental constraints and sensitivities the classification of these is as specified below:

LPA's	No-Go, non-negotiable
Dugong (IMMA)	Negotiable/Restriction Zone
Dugong 25 km buffer (IMMA)	Negotiable/Restriction Zone
IMMA's	Negotiable/Restriction Zone
Turtle Nesting Sites (incl. 5 km buffer)	No-Go, non-negotiable
Coral Reefs and Mangroves	No-Go, non-negotiable

Table 2.1 - Summary of classification of zones in Gujarat

2.2.4 Social Considerations

Potential social constraints are also being considered during the rough screening to reduce or avoid any conflict in the areas under consideration.

Social constraint mapping comprised a large variety of different topics, including:

- Marine traffic;
- Fishing industry and aqua culture;
- Cables and pipelines;
- Oil and gas platforms and exploration areas;
- Extraction of raw material and dredging;
- Military defence;
- Aviation, radar and telecommunication;
- Cultural heritage, visual impact and tourism.

2.2.4.1 Marine Traffic Considerations

Data obtained from World Bank and IMF was considered during rough screening to understand the marine traffic in Gujarat and within the selected zones. The data was categorised into commercial, fishing, oil and gas, passenger and pleasure vessels.

Based on the data, it was observed that vast majority of the traffic consisted of commercial vessels, majorly originating from the Bhavnagar port, Hazira port and Porbandar port passing through the OWF zones, which clearly indicated a significant potential conflict (See Figure 2.11). Further evaluation of the data is necessary as part of the fine screening to be able to draw comprehensive conclusions. However, it should be noted that unlike the case for Tamil Nadu, the area of interest in Gujarat lies within the territorial boundary of India and away from international marine traffic routes. As such, a prudent marine traffic planning including establishing traffic separation schemes should allow coexistence of both marine traffic and offshore wind farm.

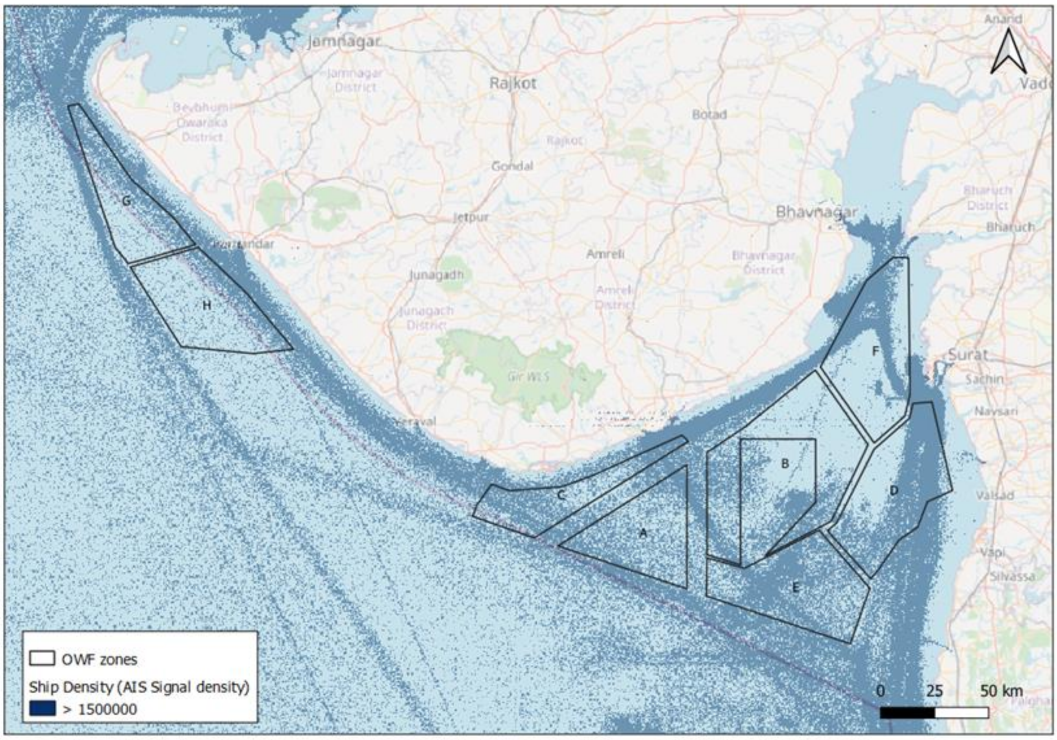

Figure 2.11 - Marine traffic in Gujarat and around the OWF zones (IMF, 2022)

2.2.4.2 Fisheries and Aquaculture

Aquaculture sites: The Gulf of Kutch area is abundant in seaweeds where several species of seaweed have been reported and is well suited for seaweed farming. The highest concentration of seagrass is observed in the areas of Paga reef, Chandri reef, Noru reef, Bhural Chank reef, Kaubhar reef, Boria reef, Mangunda reef, Goose reef and Pirotan reef in the northern coast of the Gulf of Kutch, which provides a large area for seaweed farming (See Figure 2.12).

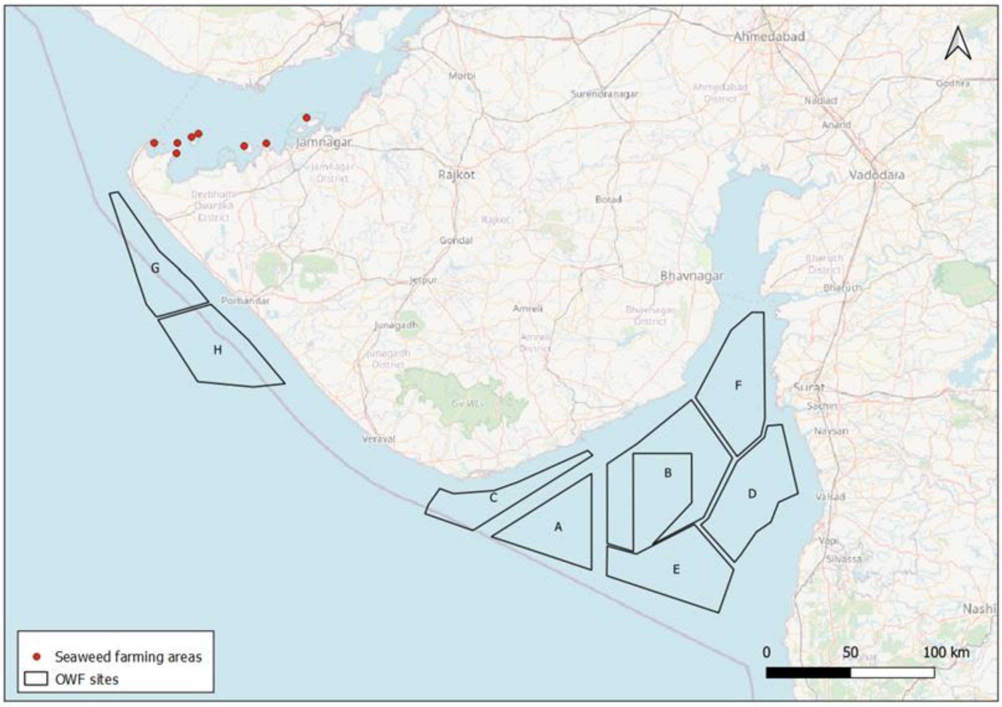

Figure 2.12 - Seaweed farming areas in Gujarat (COWI, 2022)

Fisheries: The entire coastline of Gujarat is known to be a productive ecosystem and fishing is considered to be one of the key economic activities for the surrounding population. There are seven (7) fishing harbors established by Department of Fisheries, in the areas around the selected zones which are illustrated in Figure 2.13.

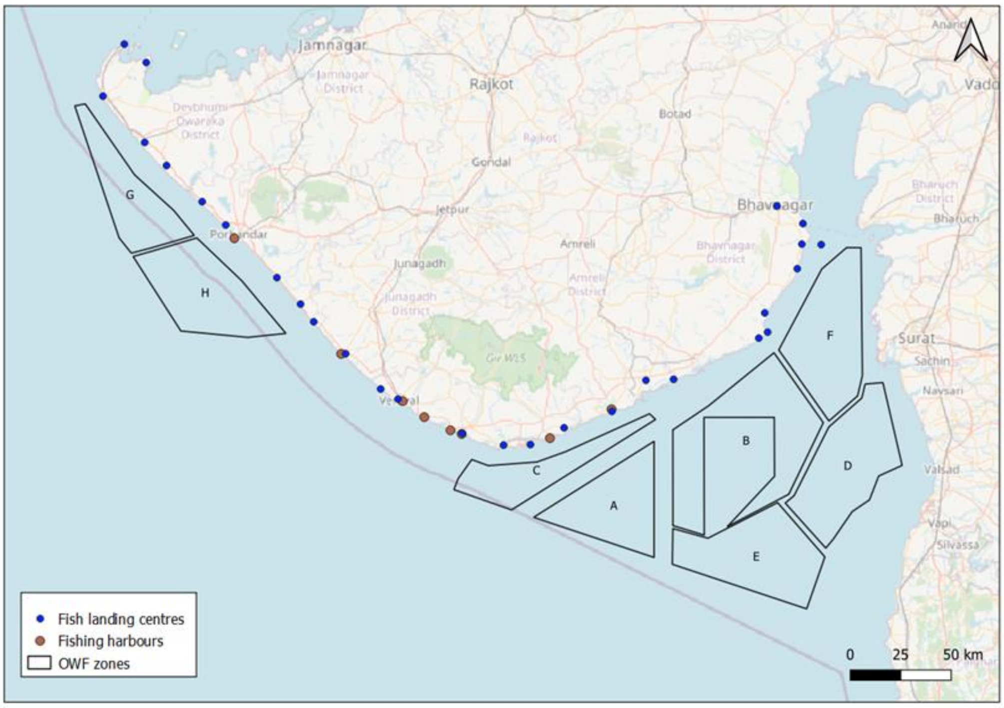

Figure 2.13 - Major fishing harbours and fish landing centres around the OWF zones (COWI, 2022)

2.2.4.3 Oil and Gas Platforms and Exploration Areas

With regard to existing oil and gas platforms and pipelines, spatial data obtained from Global Oil and Gas features database has been considered, and this illustrates that the offshore areas of Gujarat primarily lie in the Saurashtra basin. Zones B and E are observed to fall almost completely within oil fields and whereas only parts of zones A, D and F are seen to fall within oil fields.

Based on the available information, oil and gas pipelines are also seen to be intersecting through zones F and zone B (passing through the available space between zone D and E) (see Figure 2.14).

Additional maps of producing fields under Production Sharing Contract (PSC) regime (Figure 2.15) have also been considered relevant, which further confirms the presence of oil fields in proximity of the OWF zones in Gujarat.

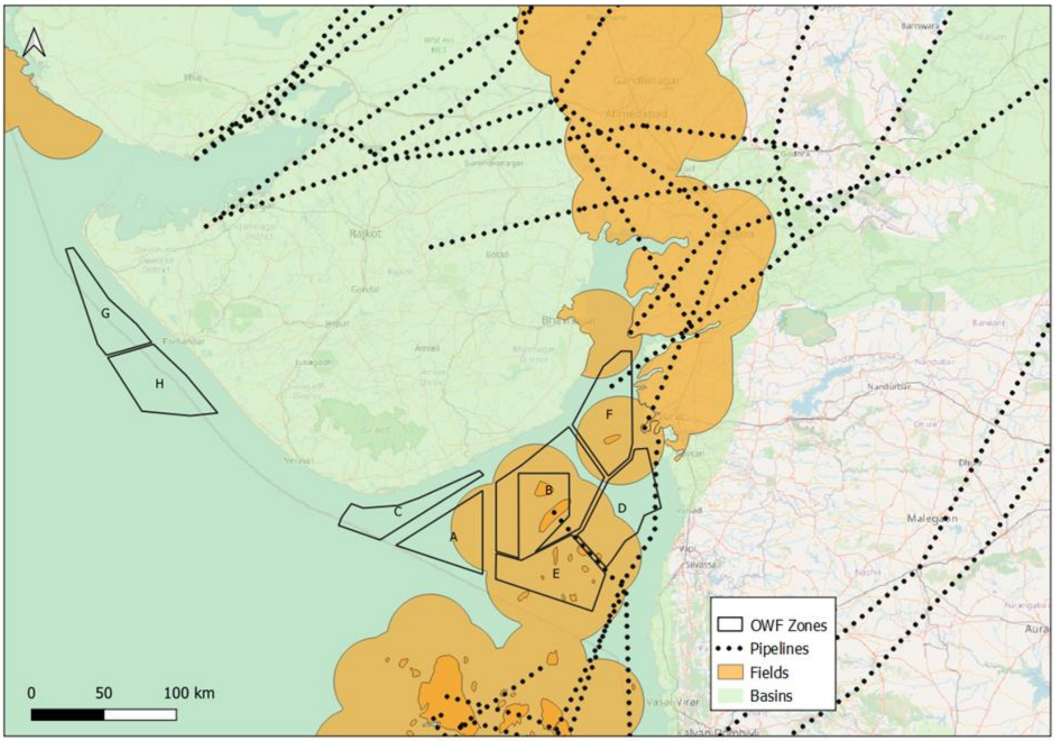

Figure 2.14 - Oil and gas pipelines, oil fields and basins in Gujarat (around OWF zones) (EDX, 2022)

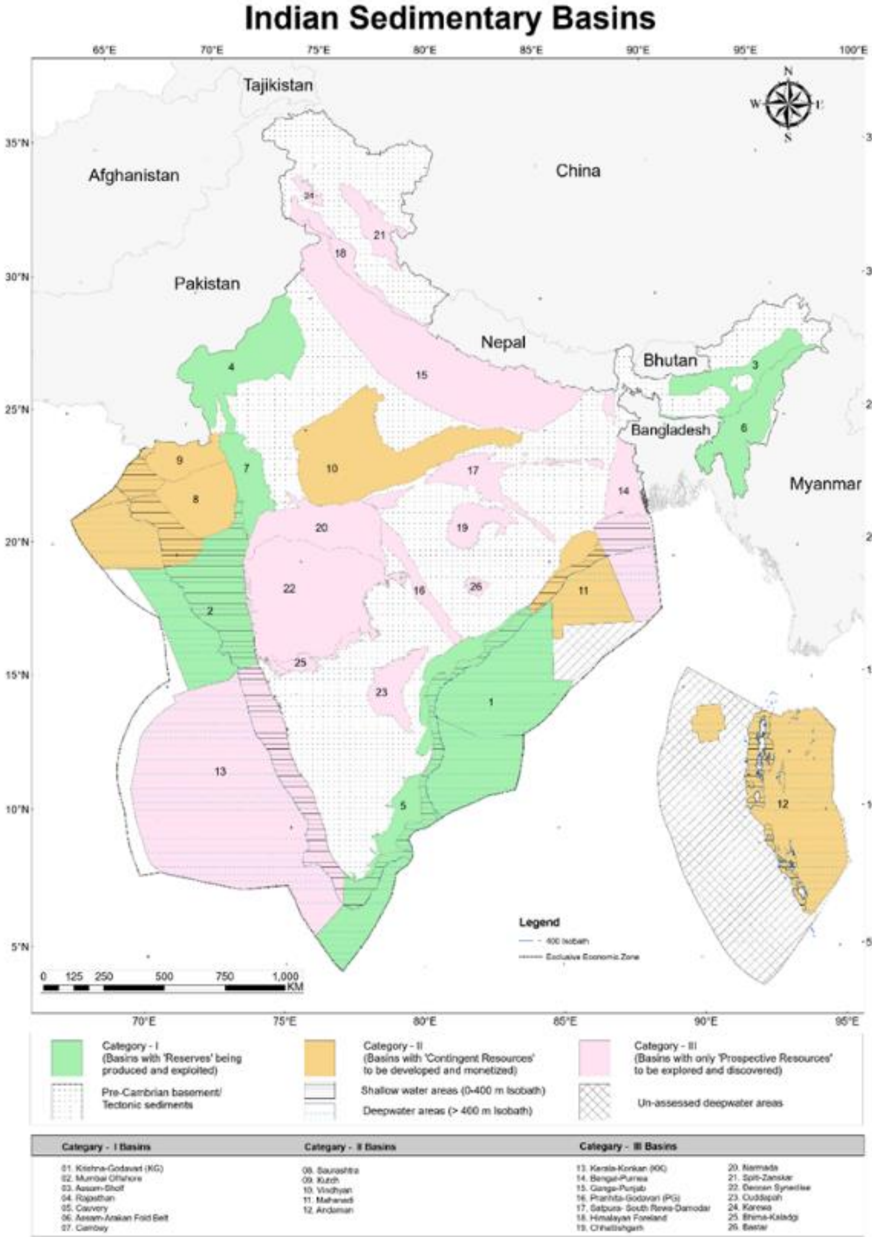

Figure 2.15 - Indian sedimentary basins (DGH, 2022)

The general area in and around Gujarat lies in the Saurashtra and Kutch Basin which comprise of active, awarded and relinquished blocks (see Figure 2.16). Most of the offshore areas and coastal areas in the Saurashtra Basin are considered to be a "re-linquished area", however offshore areas in the south of Gujarat and near the OWF zones consists of active and awarded blocks, which could be a possible constraint.

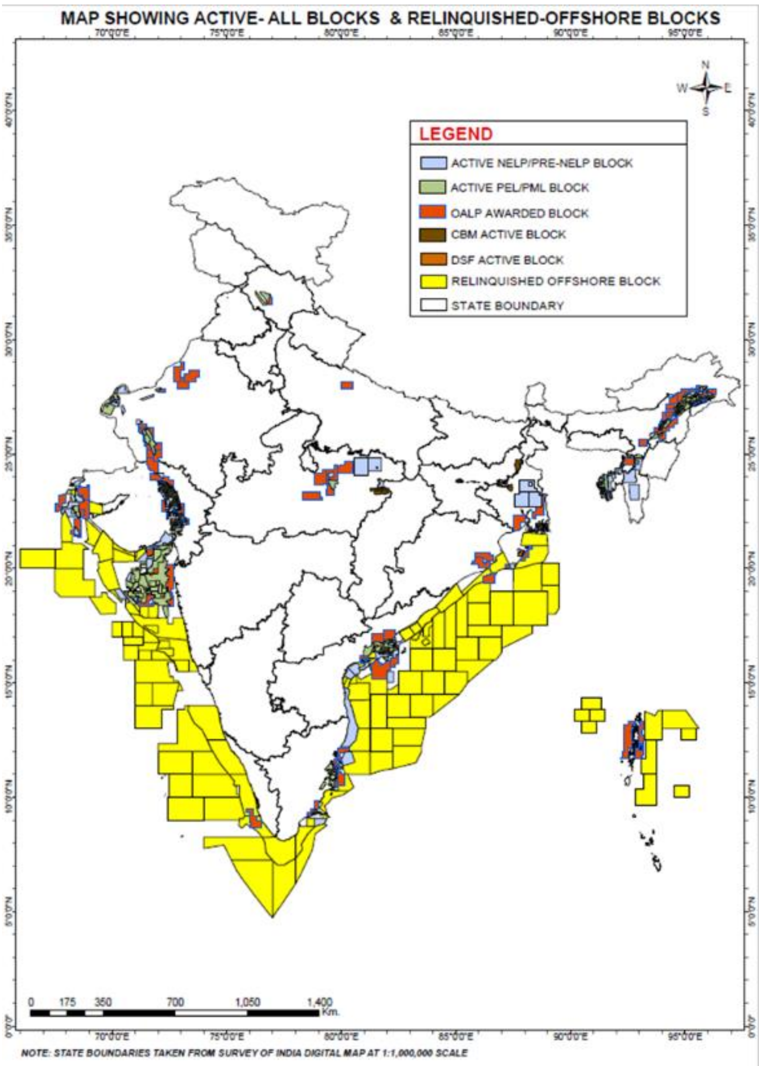

Figure 2.16 - Active-all blocks and relinquished-offshore blocks (DGH, Maps of active (all) and relinquished offshore blocks, 2022)

Therefore, further liaison with the Ministry of Oil and Natural Gas needs to be carried out to further understand the future development plans and auction rounds (if any).

2.2.4.4 Submarine communication and power cables

Submarine cables are concentrated both in the Indian Ocean and Arabian Sea. Figure 2.17 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. Based on the available information, presently no constraints were observed around the OWF zones.

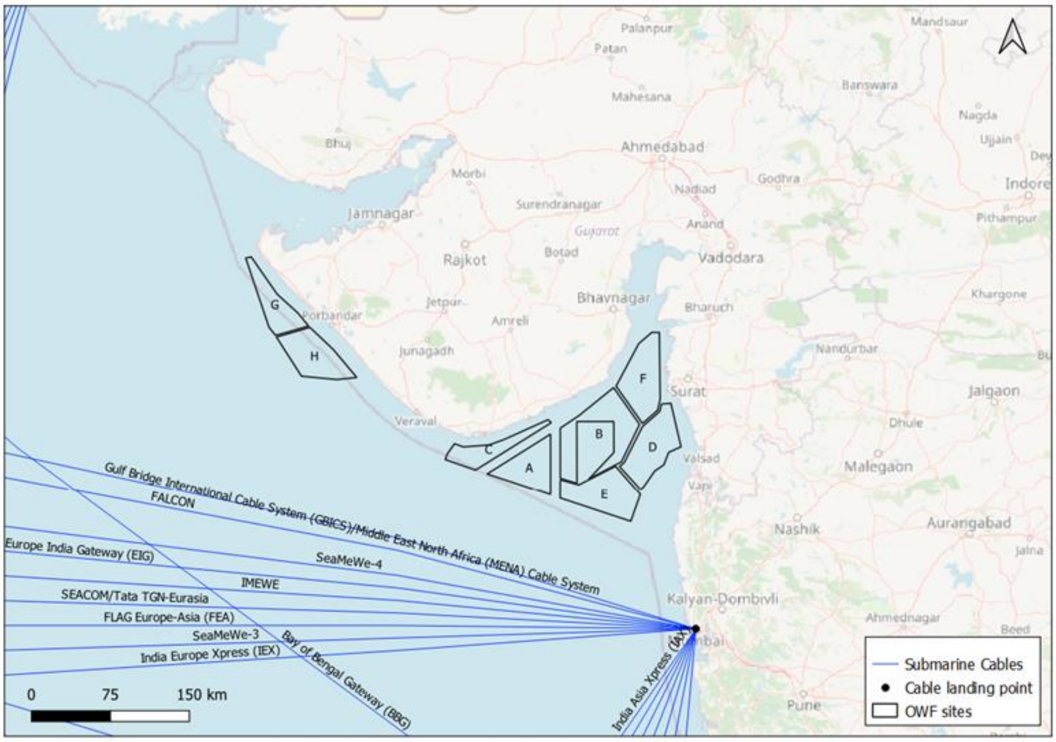

Figure 2.17 - Submarine cables near OWF zones (TeleGeography, 2022)

2.2.4.5 Military defence areas

There is high uncertainty of military activities in India since they are confidential. Some temporal activities such as laying of cables and transport of material is in many cases accepted by the military, while the operation of a windfarm is still uncertain.

It is however understood that the Ministry of Defence (MoD) has not objected to the development of offshore wind farms in the area around the selected zones, and the following zones: A, B, D, E and F have been given in-principle clearance by MoD based on previous communication. Due to potential conflicts of interest continuous communication between the relevant parties will be an essential part of the ongoing Maritime Spatial Planning.

2.2.4.6 Cultural heritage

Nine (9) sites protected by the Archeologically Survey of India (ASI) were identified (see Figure 2.18) in the rough screening which are located in proximity to the OWF zones, which are as follows:

- Bangli;
- Diu Fort;
- Juma mosque;
- Mahatma Gandhi's birth house;
- Nani Daman Fort;
- Shri Harsiddhi Mataji temple;
- Talaja caves;
- St. Pauls's Church; and

- Tower of silence.

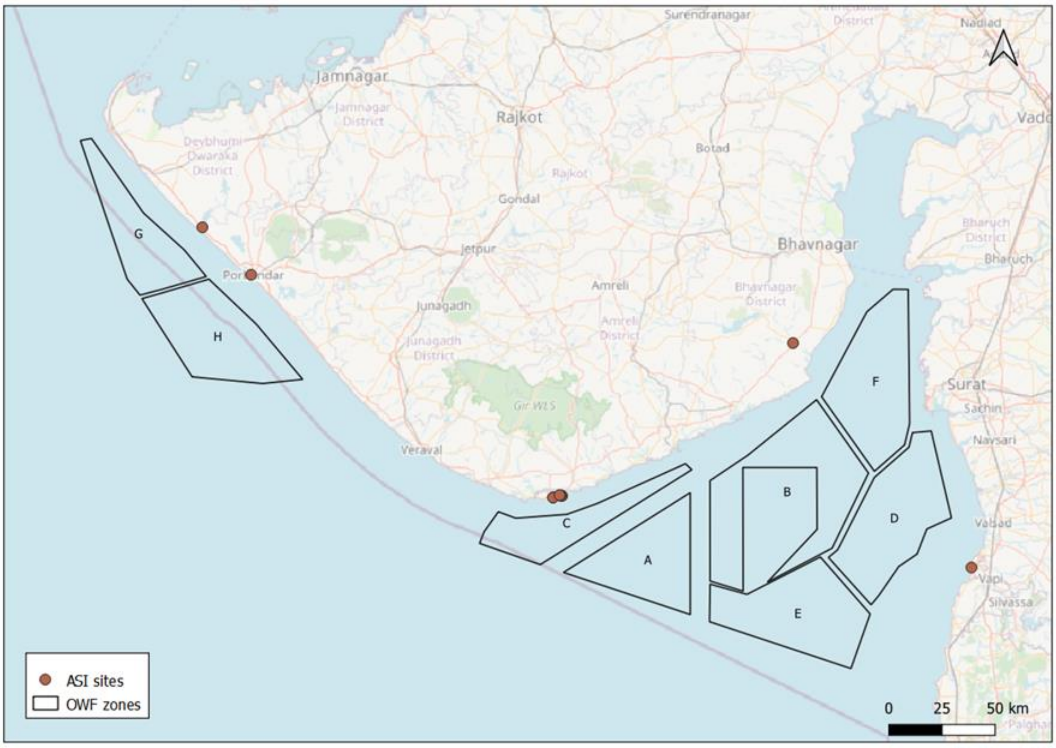

Figure 2.18 - Cultural heritage around OWF sites (COWI, 2022)

The coastal areas of Dwarka are known to have a submerged port city and therefore considered to be of great historical significance. Archaeological structural remains of early historic (1 to 7 century AD) and prehistoric periods (2nd millennium AD) century have been found in Dwarka and Bet Dwarka in northwest coast of Gujarat. Remains of the post Harrapan civilisation period (15-14th century BC) has also been re-covered from this area. (See Figure 2.19).

It is therefore recommended to undertake consultations with ASI in order to confirm the presence of any sunken remains, especially in proximity to zone G to avoid any potential conflict.

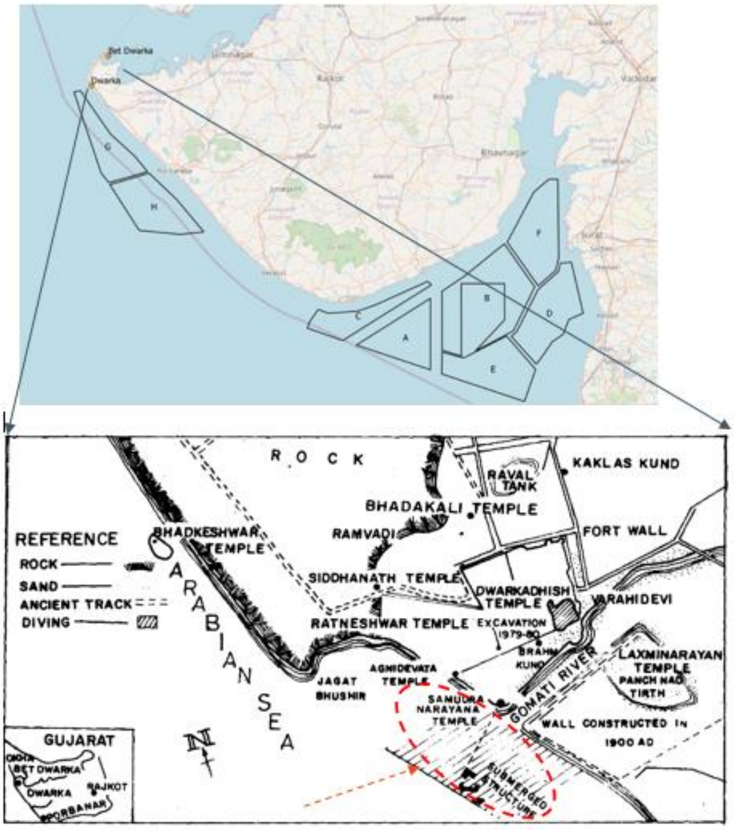

Figure 2.19 - Ancient sunken remains in Dwarka, Gujarat

2.2.4.7 Important areas for tourism/visual impact

Tourist sites identified around the selected zones are known to be of religious / cultural significance. Temples plays a significant role in the socio-cultural fabric of the community in Gujarat and are considered one of the important stakeholders for development projects in the area. Other areas for tourism include museum, castle, and beaches along the western coastline. Figure 2.20 below provides an overview of the major tourist sites identified near the OWF zones.

However, in terms of visual impacts it is still unknown as to how the offshore wind farms be viewed by the local community (as there are no precedence). This evaluation needs significant amount of stakeholder consultations, especially with the local community. Presently, this is considered to be outside the remit of this study.

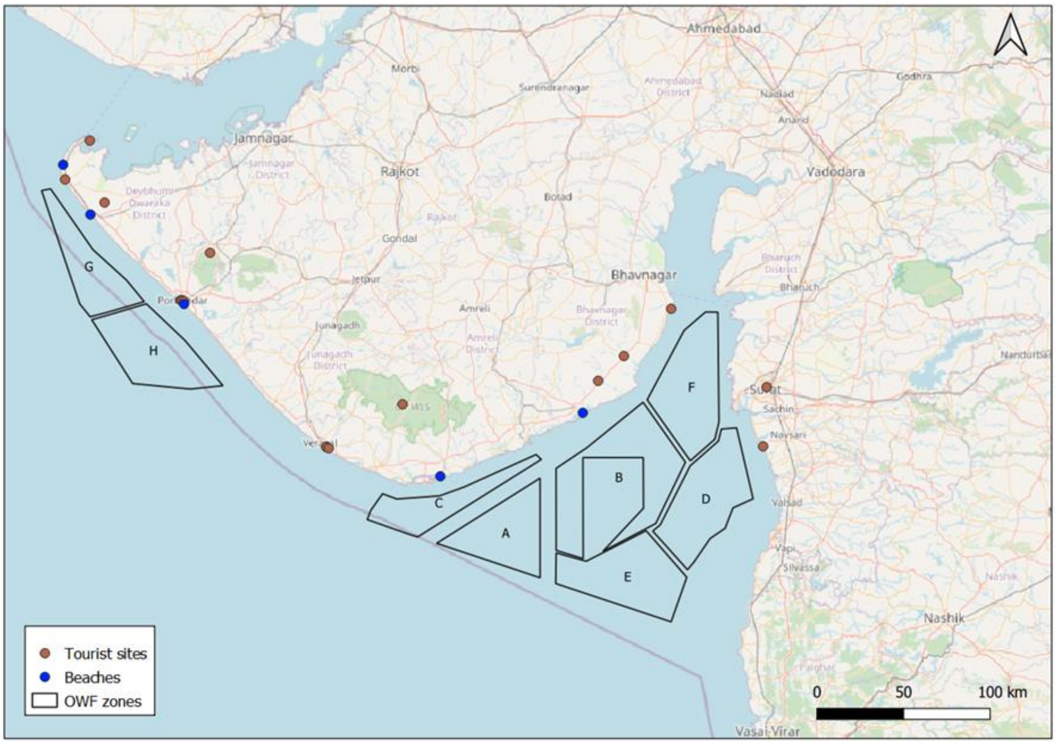

Figure 2.20 - Tourist sites around OWF zones (COWI, 2022)

2.2.4.8 Aviation, radar and telecommunication

Six (6) Radar/Air Traffic Control towers were identified in proximity of the selected zones, which are as given below and shown in Figure 2.21:

- Diu Airport;
- Surat airport;
- Porbandar airport;
- Mithapur airport;
- Bhavnagar airport; and
- Una helipad

The restriction zones around Diu, Surat and Porbandar airport are illustrated in Figure 2.22. Within these restriction zone, height restrictions are imposed, which would have significant impact of the WTG design. However, it is determined that the restricted areas around aforementioned civilian airports does not appear to pose any challenge / conflict to the development of OWF at the identified zones.

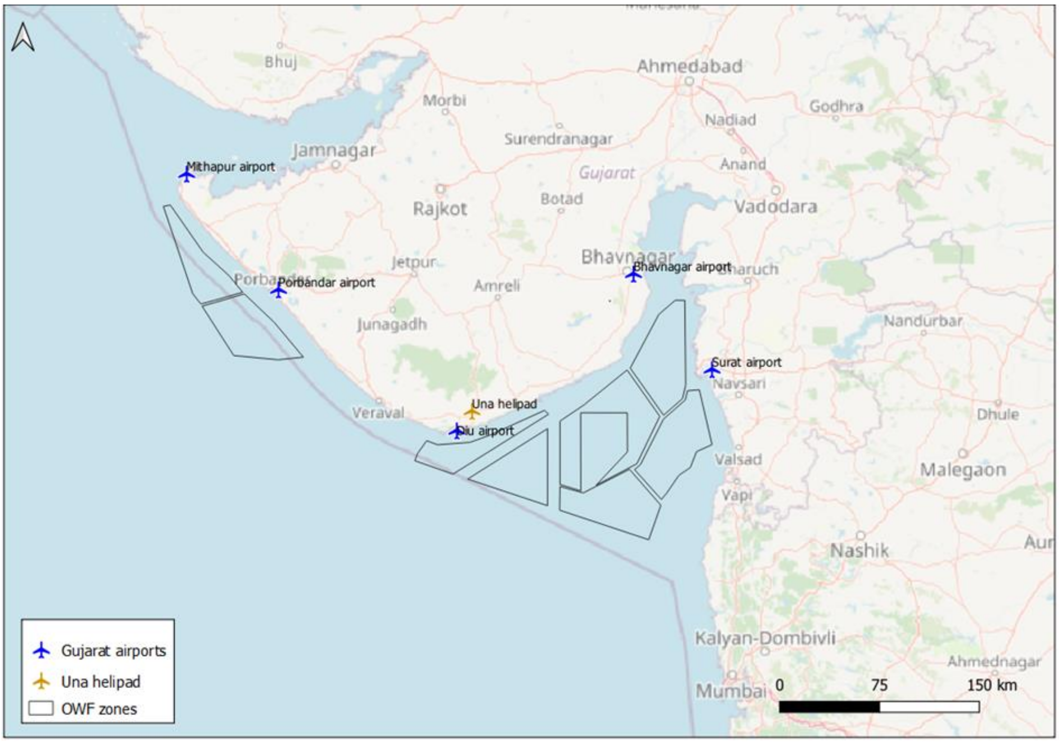

Figure 2.21 - ATC/ Radar locations near the OWF zones zones (COWI, 2022)

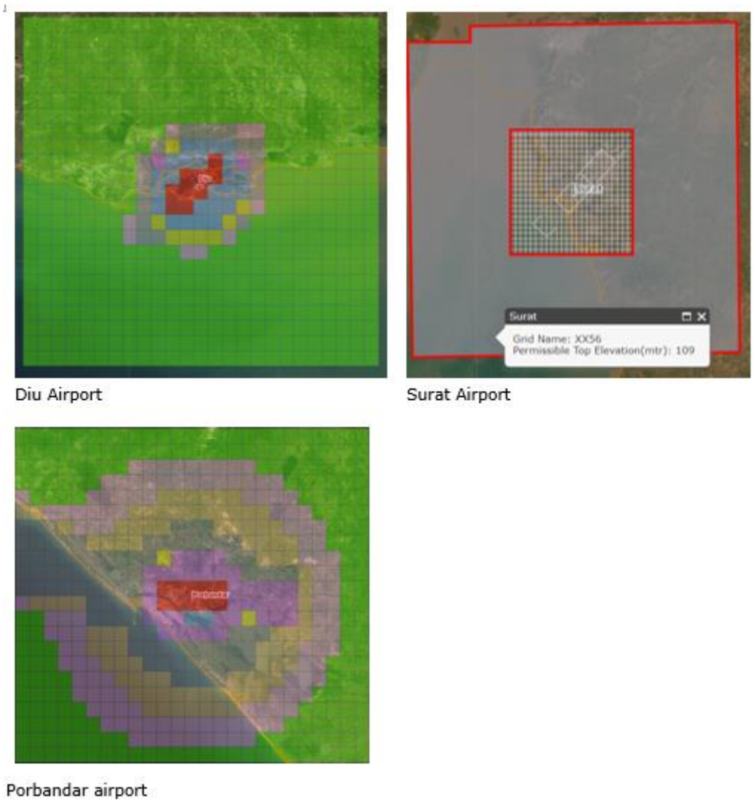

Figure 2.22 - Airport Authority of India- Restricted zone around Diu, Surat and Porbandar Airport (AAI, 2022)

2.2.4.9 Extraction of raw materials and dredging areas

No information was publicly available, which would suggest that areas within the selected zones and its surroundings are currently being used as a source of raw material and / or dredging site. Accordingly, this aspect should be further considered in later stages of development, through an Environment and Social Impact Assessment, in consultation with local stakeholders. If such sites are found to be located within the selected zones, could act as the constraint for OWF development within the shortlisted area.

2.2.4.10 Construction harbours and operational ports

A total of forty two ports including one (1) major and 41 minor ports have been identified in the Gujarat region. Out of the 41, ports potentially suitable for construction of offshore wind farm are namely:

- Pipavav Port
- Mundra Port
- Porbanadar Port
- Hazira port

The port of Pipavav is approximately 25 km from zone B and its potential to support OWF construction activities have been further evaluated during the fine screening and Maritime Spatial Planning (refer section 2.3.5 of the report). A more specific port study initiated by the Danish Energy Agency together with MNRE and NIWE is currently being performed. In that study, the suitability of the available ports is going to be analyzed in more detail for offshore wind development.

2.2.5 Grid and electrical infrastructure

In Indian context, the responsibility of electricity supply (production, transmission and distribution) is shared between both national and state governments. Power Grid Corporation of India (PGCIL) is responsible for managing the National Grid infrastructure, whereas Gujarat Electrical Transmission Company (GETCO) is responsible for erection and maintaining the grid system within Gujarat. A closer look to the southern coast of the power map of Gujarat, which contains the area of interest for offshore wind development, can be seen below in Figure 2.23.

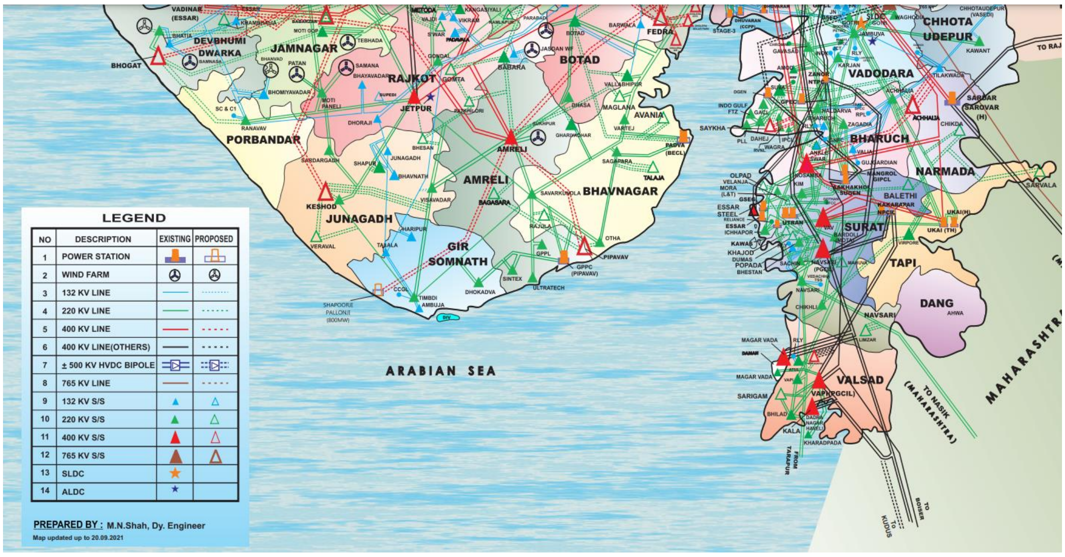

Figure 2.23 - Power Map of Gujarat (GETCO, 2021)

It can be seen from the above figure that there are mostly 220kV substations existing in close proximity to site B3. However, it can also be observed that a 400kV substation is proposed at Pipavav, which is a potential connection point for evacuation of power generated by offshore wind farms in the region.

2.2.6 Summary and conclusion

The rough screening provided a high-level overview of the potential constraints for offshore wind development in the offshore wind zones of Gujarat, based on publicly available data and information. It is however advisable to consult with the relevant stakeholders to identify any potential constraints, especially with regards to oil and gas exploration activities, military and defence activities, fishing activities and tourism within and near the zones to be able to reach a comprehensive conclusion for development of offshore windfarms in the area.

The outcome of rough screening and the key findings are summarised below.

- Wind Resource: the prevailing wind conditions at zones are considered as most favourable for development of OWF at the site with average wind speed > 7 m/s at 150m height.

- Bathymetry: the water depth ranges from 11m to 50 m and as such is considered suitable for installation of fixed foundation wind turbines.

- The key sensitive environmental habitats with high biodiversity, around the zones have been mapped based on publicly available information. The areas within the considered zones are at significant distance from the exclusion zones considered, however a small portion of Zone G and H and minor portion of zone C intersects with identified environmental restriction areas.

- Fisheries and aquaculture: The entire coastline of Gujarat and the Gulf of Kutch are considered to be highly productive for fishing. Further studies, including stakeholder consultations are required to fully understand the conflict and would be further evaluated during fine screening.

- Seismic hazard / risk: The areas are rated as moderate damage risk zone.

- Cyclone: According to the rapid EIA report prepared by NIWE in 2020 (NIWE, 2020), from 1960 to 2017, 37 depressions/cyclones crossed within a 4° radius of the project site. The maximum wind speed of these depressions/cyclones was 50 m/sand can cause storm surges up to 1.4 m

- Oil & Gas production activities: Oil and gas pipelines are seen crossing the sites. The areas also lie within and in proximity of oil fields. Therefore, further liaison with relevant stakeholders is critical to confirm this assessment and understand the potential constraints.

- Submarine and Power Cables: No submarine cables are seen crossing the OWF areas.

- Cultural Heritage and tourist areas: Cultural heritage and tourist areas including submerged/sunken villages etc. in vicinity of the zone are mapped, at present they are not considered restrictive for OFW development at the considered zones however, should be further considered at later stages of development for potential visual impacts as well as constraints that these sites may present for enabling infrastructure (such as substations)

- Defence areas: Based on previous communication the following zones: A, B, D, E and F have been given in principle clearance by MoD, and further consultation with MoD is required to identify any further potential conflict.

- Radar and Aviation: The zones are clear of any restrictions that may apply from Civilian aviation radars. However further information from military / defence radars would be required for fully understand the constraints and develop strategies for mitigation.

- Raw material and dredging areas: Currently no information is available that suggest the site is used for extraction of raw material / dredging areas. However, this needs to be confirmed during fine screening.

Marine Traffic: Significant traffic appears to originate from the Bhavnagar port, Hazira port and Porbandar port passing through the OWF zones. Therefore, commercial shipping traffic could be a potential direct conflict with the planned OWF development and requires a further assessment. However, the area of interest in Gujarat lies within the territorial boundary of India and away from international marine traffic routes. As such, a prudent marine traffic planning including establishing traffic separation schemes should allow coexistence of both marine traffic and offshore wind farm.

Figure 2.24 summarizes all the constraints mentioned during rough screening off the coast of Gujarat. It is a detailed representation of all the considerations that are taken into account before classifying them into clusters explained in Table 2.1.

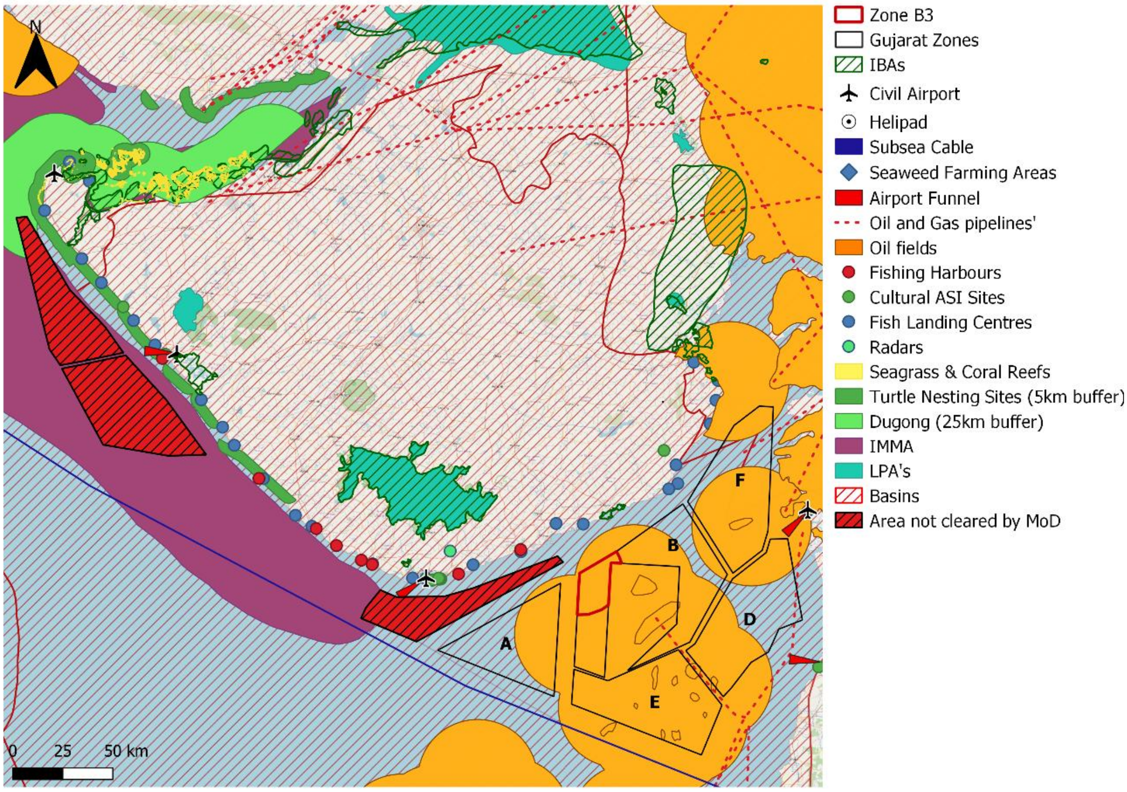

Figure 2.24 - Rough screening of coastal area in Gujarat

It can be observed in the figure that most of OWF zone G, all of H and small portion of C overlap with IMMAs. Partially the rest of the OWF zones, including the whole site area B3 lie in the buffer zone of the oil fields. It can also be observed that all of the OWF zones overlap either with the oil & gas basin areas of Mumbai Offshore, which is a Category-I type of basin with reserves and already producing, or with Saurashtra-Kutch, which is a Category-II type of basin having contingent resources pending for commercial production. (DGH, 2022)

This observation is used in Figure 2.25 , where all the information is translated into a classification of the offshore area according to the criteria assessed during rough screening.

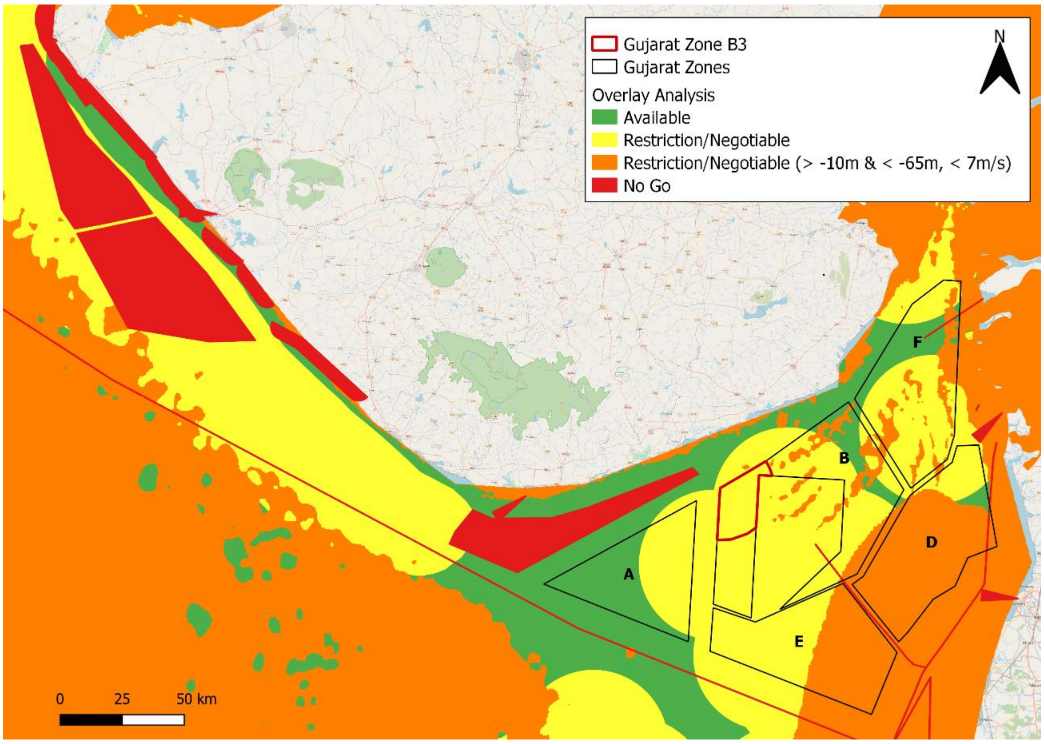

Figure 2.25 – Traffic light classification of offshore wind zones resulted from rough screening of coastal area in Gujarat

It can be seen in the above figure that the offshore wind zones are polygons plotted with a black border which are determined in the pre-feasibility report. A traffic light scheme is used to classify different sections of the whole coastal area with the representation of different colors explained in the legend of the figure. Areas specified as "No-Go" with red color are the LPAs, turtle nesting sites with 5 km buffer around them and areas for coral reefs and mangroves, which were mentioned as exclusion zones. Areas not cleared by MoD such as OWF zones C, G and H are also classified as "No-Go". Areas specified as "Restriction / Negotiable" with yellow color are IMMAs and areas reserved for Dugong marine mammals with 25 km buffer around them especially covering the OWF zones of G and H as well as oil fields in zones A, B, D, E and F. In addition to exclusion and restriction zones, areas specified as "Restriction / Negotiable" with orange color are reserved for setting the boundary for best conditions for fixed-bottom foundation turbines taking bathymetry and wind speed into consideration. This means that most of zone D and parts of zones E and F are not assessed to be suitable for fixed-bottom offshore wind turbines. Finally, the oil and gas basins are represented with a shaded area in order to specifically emphasize borders overlapping with offshore wind zones. They are basically covering the whole area so at this stage they will be highlighted for future analysis but will not be categorized. Further consideration on the zones represented with yellow and green color will be taken in the fine screening process in the next section.

2.3 Fine Screening

2.3.1 Marine Traffic Considerations

In order to obtain a comprehensive picture of the marine traffic in and around the OWF zones, AIS data has been extracted from datacatalog.worldbank.org and has been analyzed. The dataset contains 6 density layers, with vessel types aggregated to suit the needs of the WBG Offshore Wind Development Program:

1) Commercial ships
2) Fishing ships
3) Oil & Gas [note: this is just platforms, rigs, and FPSOs]
4) Passenger ships
5) Leisure vessels
6) GLOBAL ship density layers of all ship categories combined

The raster layers were created using IMF's analysis of hourly AIS positions received between Jan-2015 and Feb-2020 and represent the total number of AIS positions that have been reported by ships in each grid cell with dimensions of 0.005 degree by 0.005 degree (approximately a 500m x 500m grid at the Equator). These AIS positions may have been transmitted by both moving and stationary ships within each grid cell, therefore the density is analogous to the general intensity of shipping activity.

The collected data signals for Gujarat region are plotted below in Figure 2.26 with higher intensity regions having red color compared to low intensity regions having lighter blue color as indicated also in the legend.

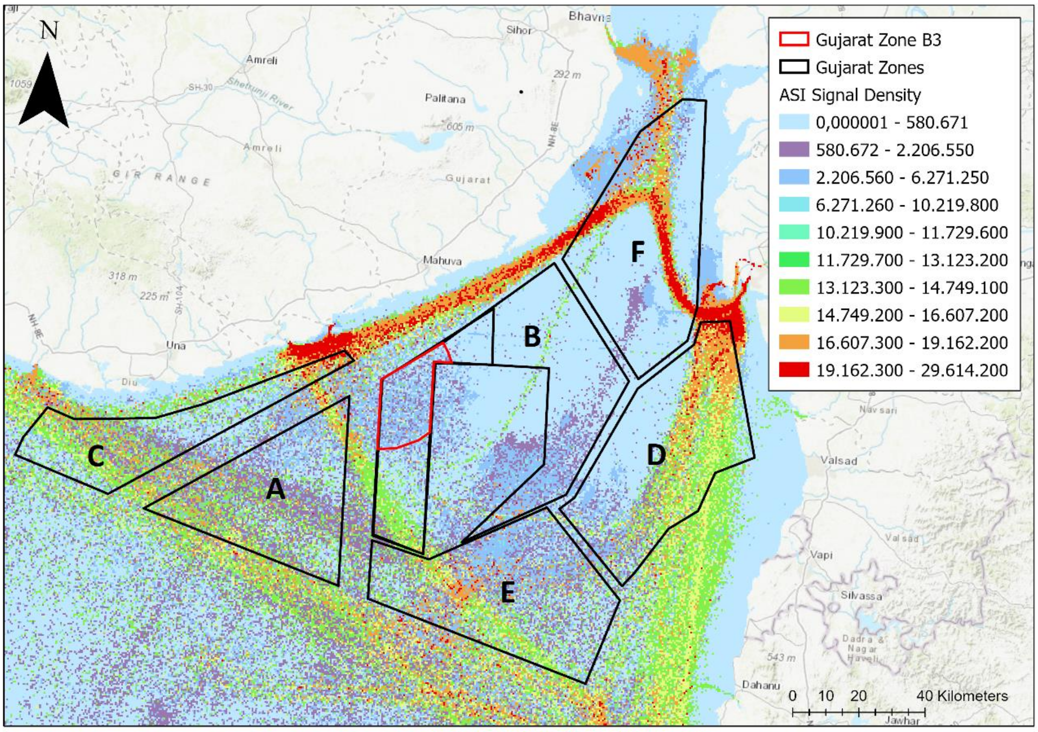

Figure 2.26 - Marine Traffic Density Map Based on AIS data

The borders of the OWF zones have been drawn during the assessment in the prefeasibility report (FOWPI, 2015) with distances between the site borders allocated while taking various environmental and social factors into consideration. One of those factors were the navigational corridors allocated for vessels and boats operational in the area especially between OWF zones A, C, B and E. However, as mentioned during rough screening, the more updated analysis in Figure 2.26 shows that vessel traffic is actually not very consistent with the navigational corridors in the prefeasibility report, and there are more conflicts with some of the OWF zones. Therefore, a more detailed vessel traffic analysis with tracks of individual journeys of each individual vessel being plotted as lines will be necessary in order to be able to assess the marine traffic intensity in the region. This type of analysis might lead to a reassessment of the OWF zone borders in order to be able to use the space more efficiently while preventing any risks brought by vessel traffic.

2.3.2 Considerations regarding Oil & Gas Platforms and Exploration Areas

Section 2.2.4.3 provided a general look on the oil & gas platforms as well as exploration areas off the coast of Gujarat. It was mentioned in that section that most of the offshore areas and coastal areas in the Saurashtra Basin are considered to be a "relinquished area", however offshore areas in the south of Gujarat and near the OWF zones consists of active and awarded blocks, which could be a possible constraint.

In order to get a better picture of this constraint, a more detailed look in the region especially into the sedimentary basin named "Mumbai Offshore" in Figure 2.15 is necessary. Initially, it can be seen from the maps published by DGH, Directorate General of Hydrocarbons, that there are different policies and programs that the basins are awarded to different entities, and these needs to be considered as stakeholders if conflict of interest in the offshore wind zones can arise.

One of these policies is "Discovered Small (Marginal) Field Policy" also named as DSF. In line with the vision of "ease of doing business" a simple and easy way to administer contractual model of revenue sharing is introduced wherein the government's take is based on bid revenue share. This policy enables operational autonomy to developers and reduced micromanagement by the government, who acts an auditing body for production and revenue aiming to reduce disputes, easing approval process while operator is focusing on reducing costs. First DSF round was launched in 2016 with 46 contract areas and 67 fields across nine sedimentary basins for extraction and exploration of oil & gas. These areas and fields can be seen below in Figure 2.27.

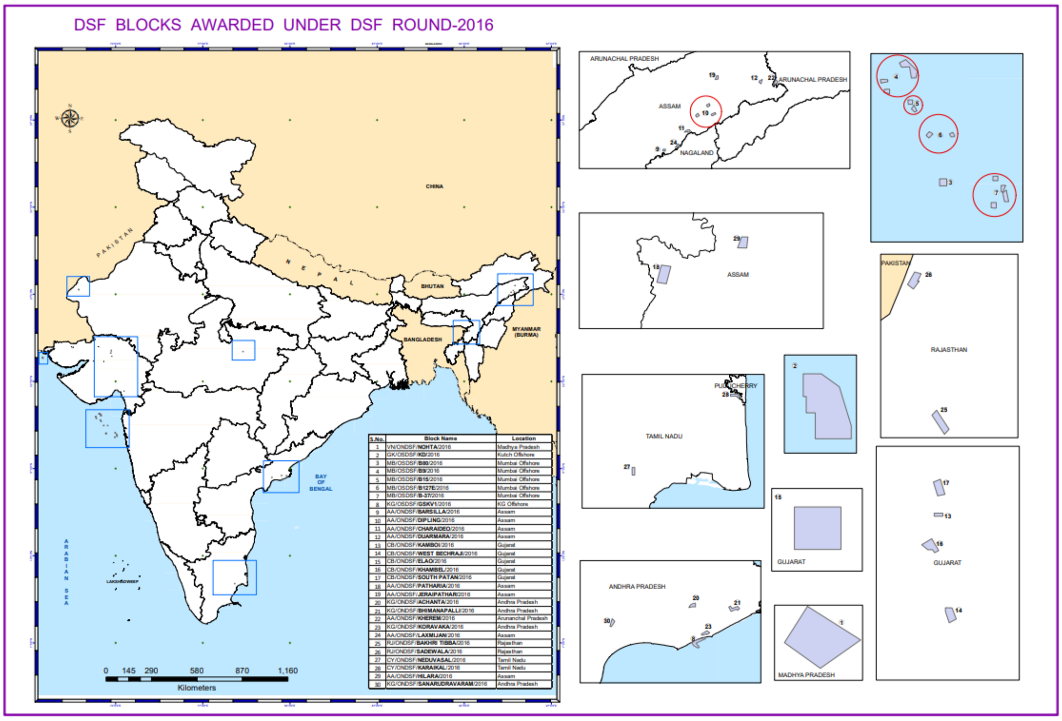

Figure 2.27 - DSF Blocks Awarded Under DSF Round-I in 2016 (DGH, 2022)

As can be observed from the figure, some of the areas are very close to Gujarat coast and are potentially in conflict with OWF zones. These areas should be investigated further in terms of their risk for offshore wind development. Same can be observed for DSF Round-II awarded areas, which can be seen in Figure 2.28.

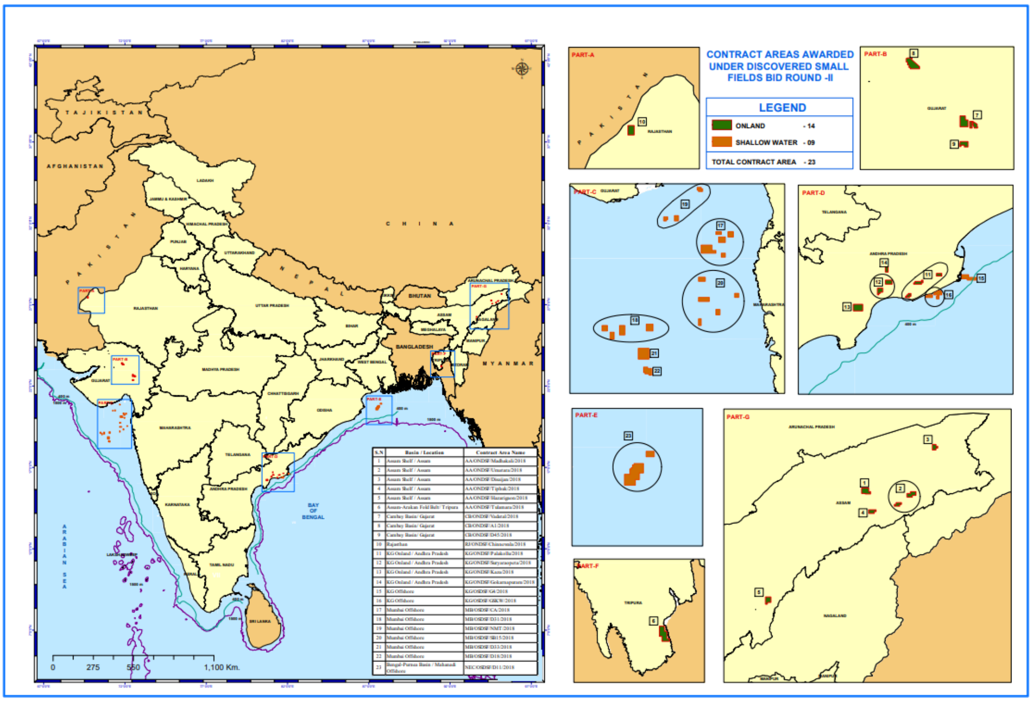

Figure 2.28 - DSF Blocks Awarded Under DSF Round-II in 2019 (DGH, 2022)

DSF Round-III locations, for which the bid submission start has been officially announced, can be seen below in Figure 2.29. Again, a more detailed analysis of the risk for conflict of interest with OWF zones should be investigated.

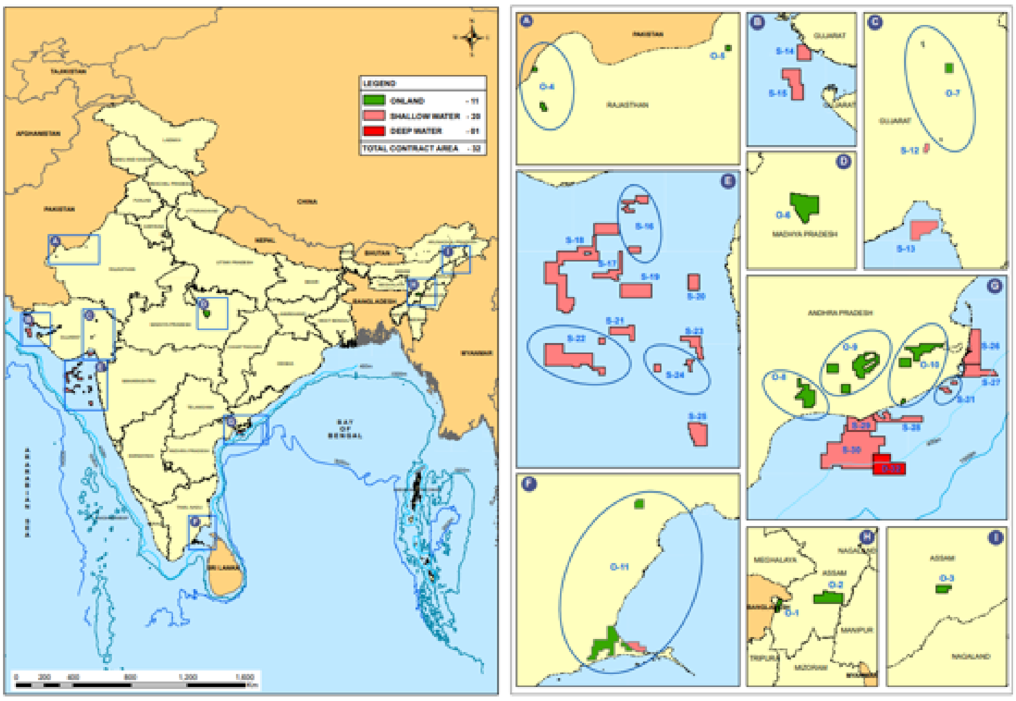

Figure 2.29 – DSF Contract Areas on Offer for Bid Round-III (DGH, 2022)

Another program initiated by Ministry of Petroleum and Natural Gas used for oil & gas exploration and extraction is called the Open Acreage Licensing Program (OALP), which allows the investors to carve out blocks of their choice by assessing E&P data available at NDR & by submitting an Expression of Interest (EoI). EoI can be submitted throughout the year without waiting for a formal bid round from the government. These blocks would be subsequently offered through biannual formal bidding process since 2018. The last OALP Round-VIII bids were launched in July 2022 and will be closed at the end of October 2022.

The blocks awarded in OALP Bid Round-I and Round-III are identified to be in close proximity to the OWF zones in Gujarat coast. They can be seen below in Figure 2.30.

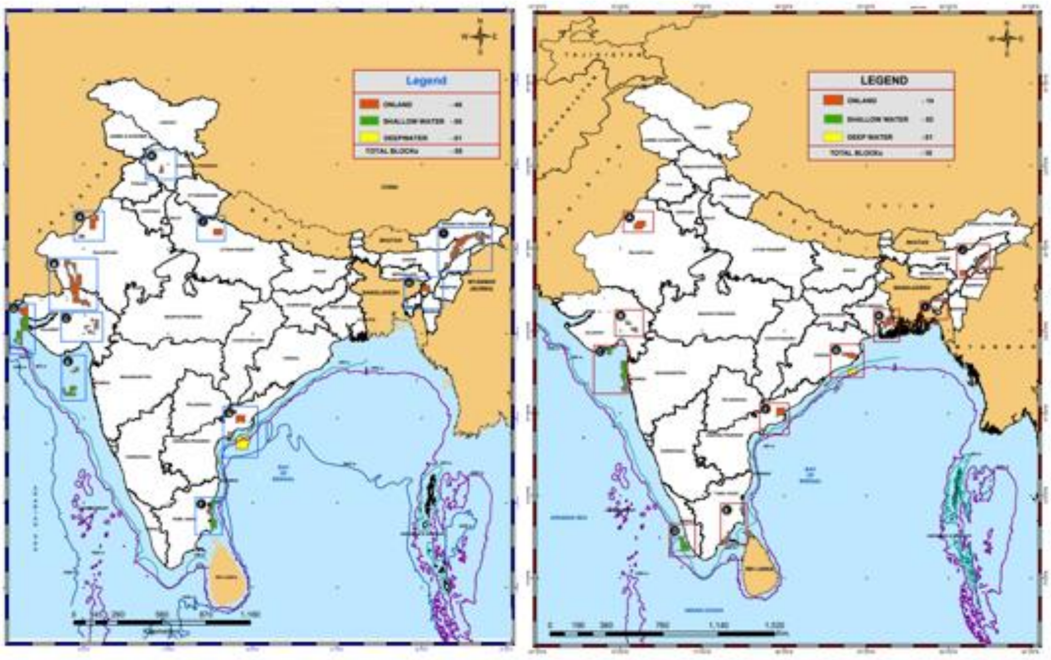

Figure 2.30 – OALP Bid Round-I Awarded Areas (Left), OALP Bid Round-III Awarded Areas (Right) (DGH, 2022)

Especially the site named S1 in OALP Bid Round-III is very close to the OWF zone B3 in Gujarat sharing a border on the side close to the shore. This kind of close proximity can cause higher uncertainty for offshore wind development in terms of feasibility as well as installation and maintenance operations. It will be important to assess this risk of conflict of interest that can be highly likely for this area.

Figure 2.31 below is a close-up of Figure 2.16 to the coast of Gujarat with the legend included indicating DSF and OALP blocks. It can be seen from the figure that there are many active blocks under different licensing schemes apart from the ones mentioned previously. Among these ones are the blocks that are awarded petroleum exploration licenses (PEL), which are granted for a period of 7 years in inland/shallow water areas and for 8 years in deep water and frontier areas under the new exploration licensing policy (NELP) and petroleum mining licenses (PML), which are normally awarded for a period of 20 years.

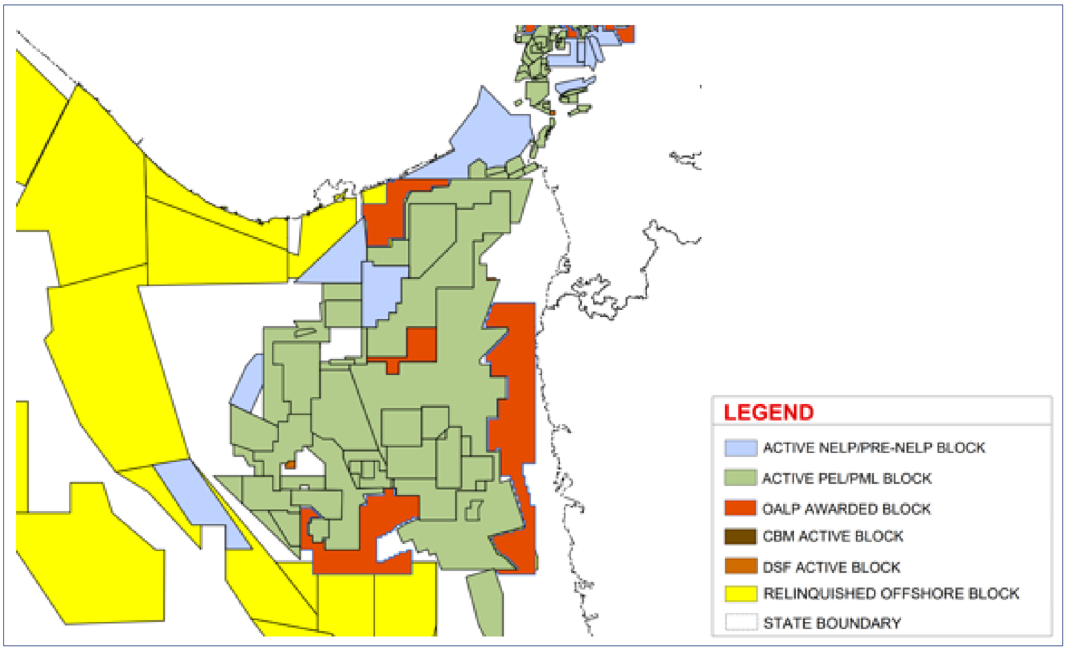

Figure 2.31 - Close up of sedimentary basins in coast of Gujarat (DGH, 2022)

All these active blocks in Figure 2.31 are currently overlaying with the zones allocated for offshore wind development off the Gujarat coast. It will be beneficial to identify safety distances during operation and installation, possibility and rules for laying cables or any interference of vessel operations in order to be able to assess the coexistence of these two industries. This means that liaison with Ministry of Petroleum & Natural Gas on this issue is of great importance.

Another important point that needs attention is the reasoning behind the exclusion of the oil & gas block in the middle of OWF zone B in the prefeasibility report. It can be observed in that report that the area in the middle of zone B is identified as a "No-Go" area and isn't considered as part of Zone B that can be used for offshore wind. It will be necessary to identify the reasoning behind this logic to highlight if the other blocks carry the same risk or if this excluded area during the prefeasibility report can now actually be considered as part of the area to be used for offshore wind development.

2.3.3 Wind Climate

A LiDAR based offshore measurement campaign was commenced on November 2017 in Zone B, Gulf of Khambhat, off Gujarat coast, which is first of its kind in the country and its location can be seen in Figure 2.32. The measurements are still underway. 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. In continuation with the First Offshore LiDAR Wind data analysis report, the second year data for the period from December 2018 to November 2019 has been analyzed and reported again by NIWE and is available on the website. This section will highlight the main findings from that report in terms of wind climate, but more details can be found in the original report.

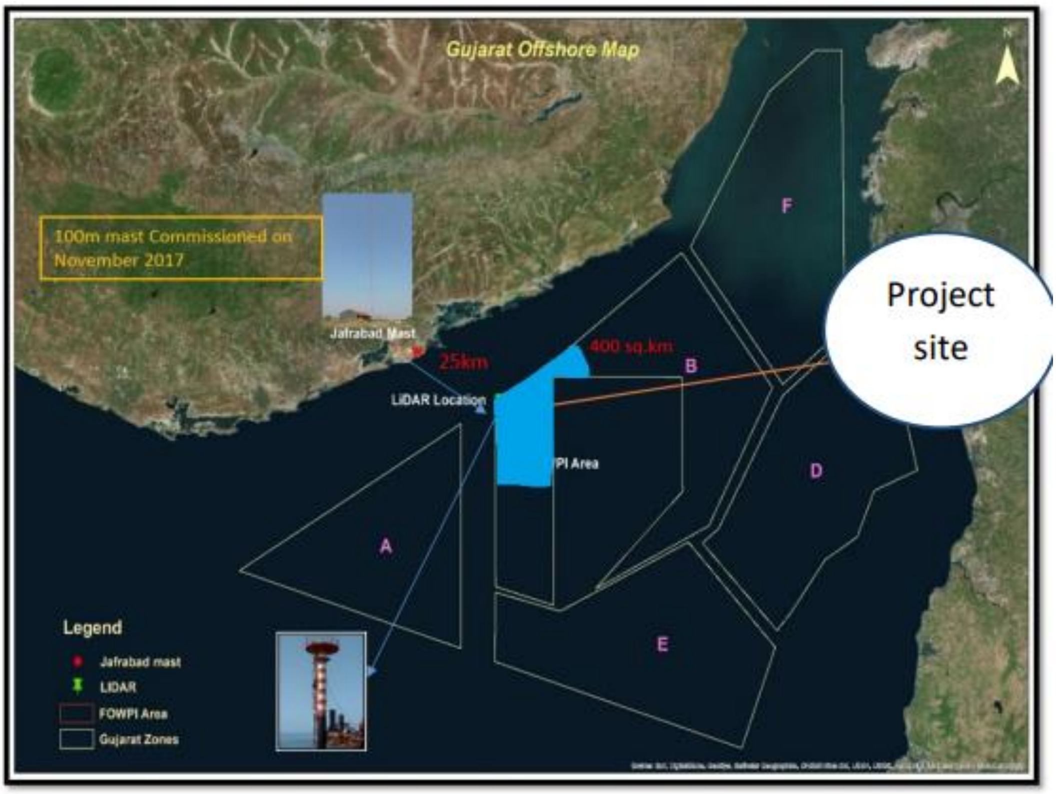

Figure 2.32 - Lidar Location off Gujarat coast (NIWE, 2019)

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 2.33 and Figure 2.34. It should be noted that the missing wind speed data from Dec-2018 to Nov-2019 has been synthesized by using 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 measurement by using LLS (Least Linear Square) algorithm. The correlation coefficient of determination (R^2) between LiDAR data and Coastal mast data was estimated above 0.85, which seems to be a good correlation. Correlation coefficient of determination between LiDAR data and coastal mast data can be seen in the original report.

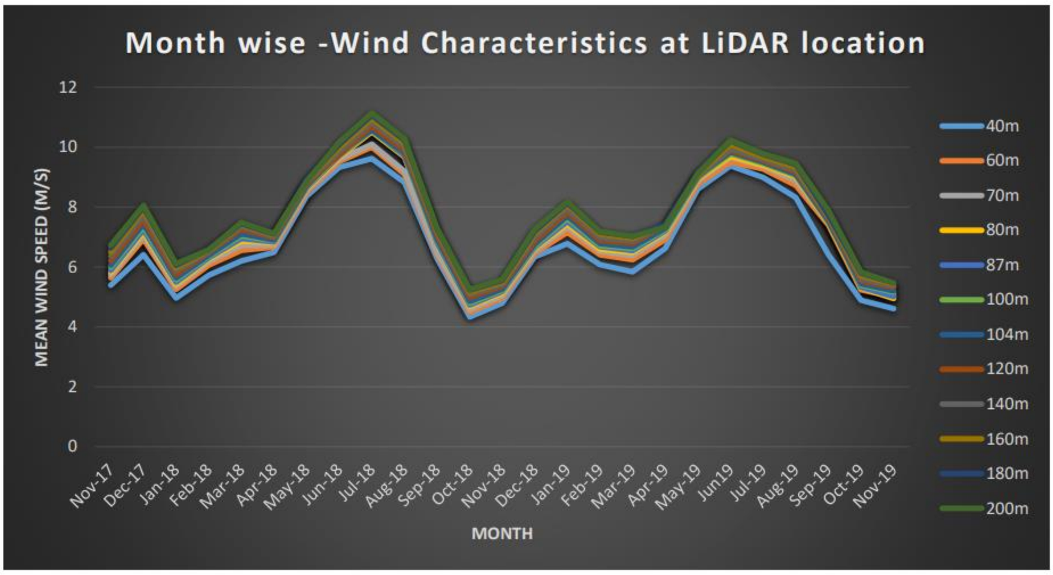

Figure 2.33 - Mean wind speed measurements on a monthly basis (NIWE, 2019)

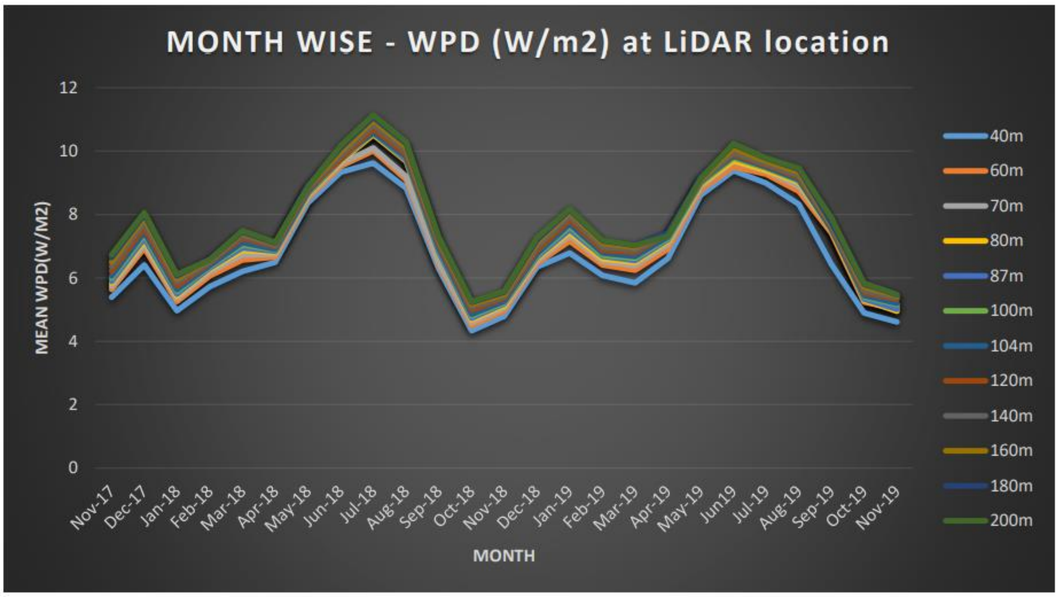

Figure 2.34 - Mean wind power density on a monthly basis (NIWE, 2019)

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 height, 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 floating lidar measurements is expected to be lower than the mesoscale model used in the wind atlas, however the second year measurements being completed using the MCP technique adds another level of uncertainty and therefore should be assessed further and preferably quantified.

Wind rose for all measured heights can be seen in Figure 2.35 for first year measurements and in Figure 2.36 for second year measurements.

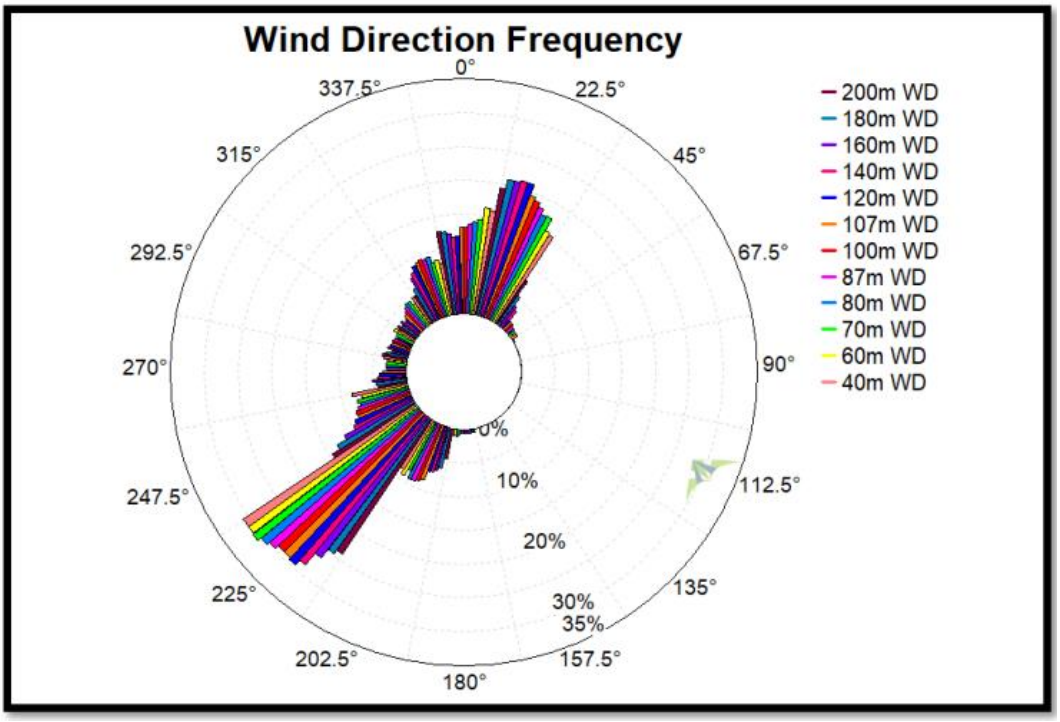

Figure 2.35 - Wind direction for all measured heights between Nov-2017 and Nov-2018 (NIWE, 2019)

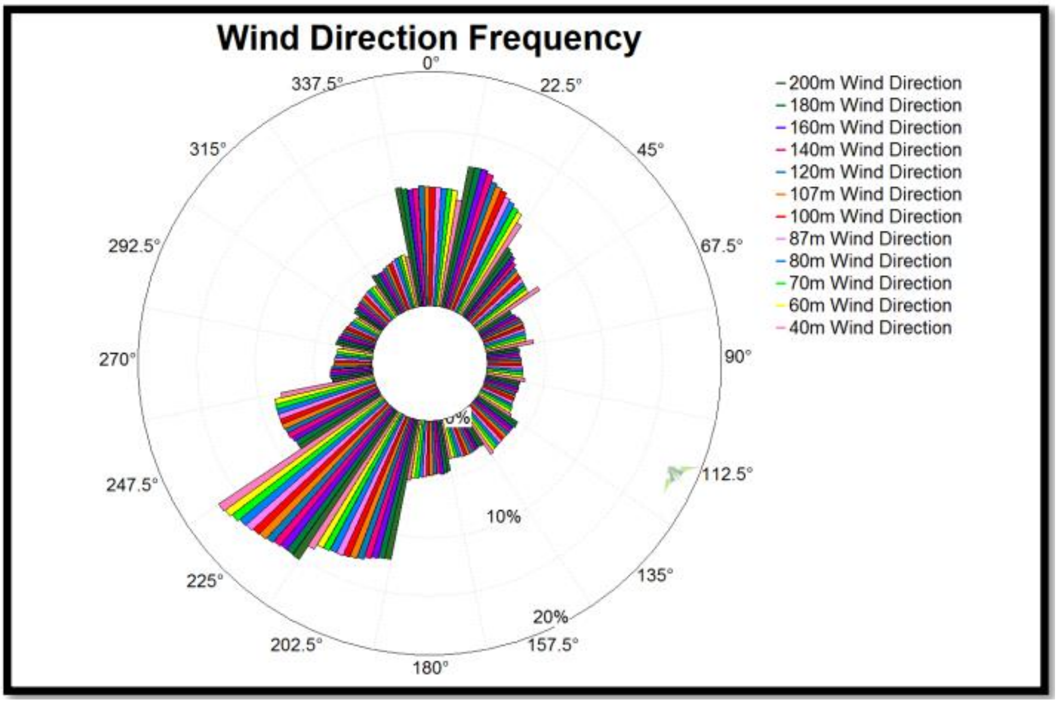

Figure 2.36 - Wind direction for all measured heights between Dec-2018 and Nov-2019 (NIWE, 2019)

Based on the second year data, it is observed that the primary prevalent wind direction is SSW (south of south west) with wind speed occurrence about 15.8% and secondary prevalent wind direction is N (North) with wind speed occurrence about 11.1%.

The annual average wind speed values observed in 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 2.33 and Figure 2.34. 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 with average being 6.7 m/s at 160m height above sea level between Nov-2017 to Nov-2018 and 6.93 m/s at 160 m height above sea level between Dec-2018 and Nov-2019. 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.

In terms of extreme weather phenomena, according to the rapid EIA report prepared by NIWE in 2020 (NIWE, 2020), from 1960 to 2017, 37 depressions/cyclones crossed within a 4° radius of the project site. The maximum wind speed of these depressions/cyclones was 50 m/sand can cause storm surges up to 1.4 m. A cyclone hazard map of Gujarat can be seen in Figure 2.37.

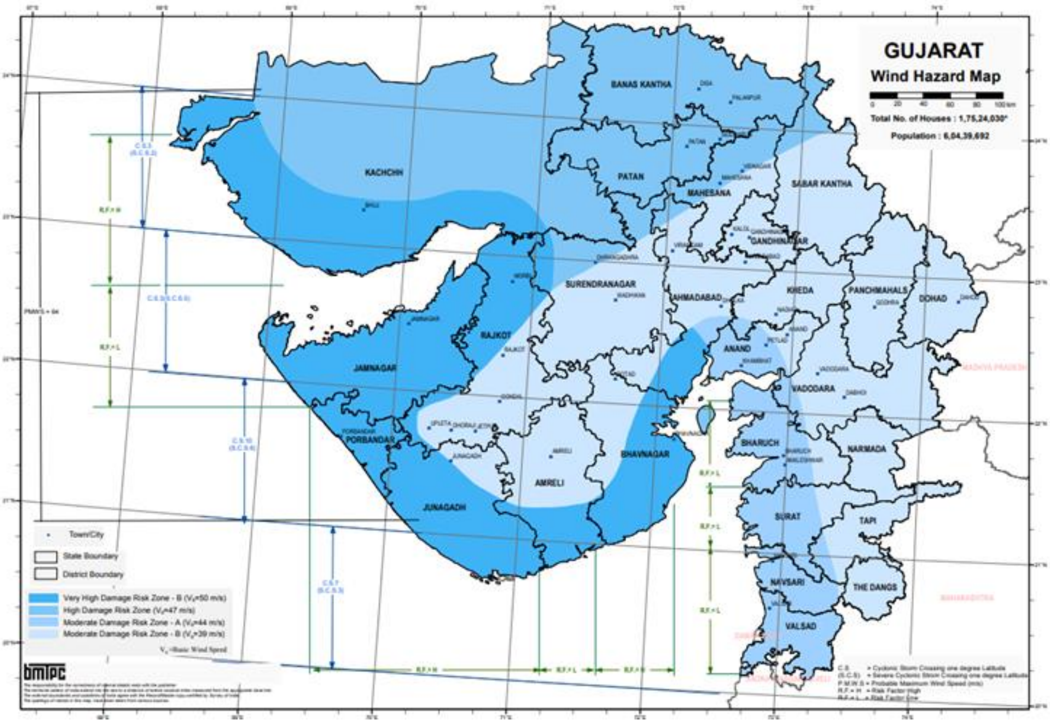

Figure 2.37- Wind hazard map of Gujarat (Building Materials & Technology Promotion Council, 2022)

2.3.4 Seabed Screening

The main objective of this section is to undertake a seabed screening offshore the Gujarat region. This thematic sub-report contains a preliminary assessment of the seabed, geology, and subsea conditions offshore Gujarat. The assessment is based on publicly available data, COWI in-house data and literature.

2.3.4.1 Data

There exists a large amount of geophysical data from the screened area, mainly due to oil and gas exploration and production in the area. The data consists of 2D and 3D seismic surveys as well as many exploration wells which all are stored at the Indian National Data Repository (NDR). However, these data are confidential and can only be assessed via confidentiality agreements and purchases and cannot be included as basis for this screening. (National Data Repository, 2022)For future offshore wind studies of the Gujarat area, access to these data would be very beneficial as a conceptual geological model for the area could be developed and used for more robust technical recommendations. Several relevant articles and reports have been identified and are referred to in the reference list. Internal COWI data are confidential and cannot be referenced but have supported the public available data and literature.

The main available data that have been used as basis for the screening are:

- Bathymetry – grid from Global Wind Atlas
- Seafloor geomorphology – data from ESRI
- Seabed features e.g., basins, ridges, and canyons – data from EMODnet
- Internal geophysical and geotechnical COWI data

Bathymetric data is provided with a zonation of water depth encircling areas with water depths less than 10 m, from 10-20 m, 20-30 m, 30-40 m, and 40-50 m within the area of interest (AOI). Overall, the water depth varies from 1-50 m in the area of interest. Fixed bottom wind turbines are economically feasible at water depths up to approximately 65 m and could therefore be a potential possibility.

2.3.4.2 Seabed Morphology

The Gulf of Cambay in the southern part of the State of Gujarat has several large rivers draining into it. To the south, the Gulf is adjacent to the main Arabian Sea. The majority of the area is located on the shelf where the water depths are feasible for OWF.

The river sediment discharge has resulted in the formation of several long linear sandy shoals which superimposes the surrounding clayey formations. Comparison of historical mapping indicates that the seabed is very dynamic with the formation of sand bars, levees, mud flats and islands, in addition to the movement of the sandy shoals.

Several north-northeast to west-southwest trending basins and shelf valleys have been identified based on ESRI data in Figure 2.38. The basins and shelf valleys are all located in the eastern part of the AOI and account for the large variations in the geomorphology observed here.

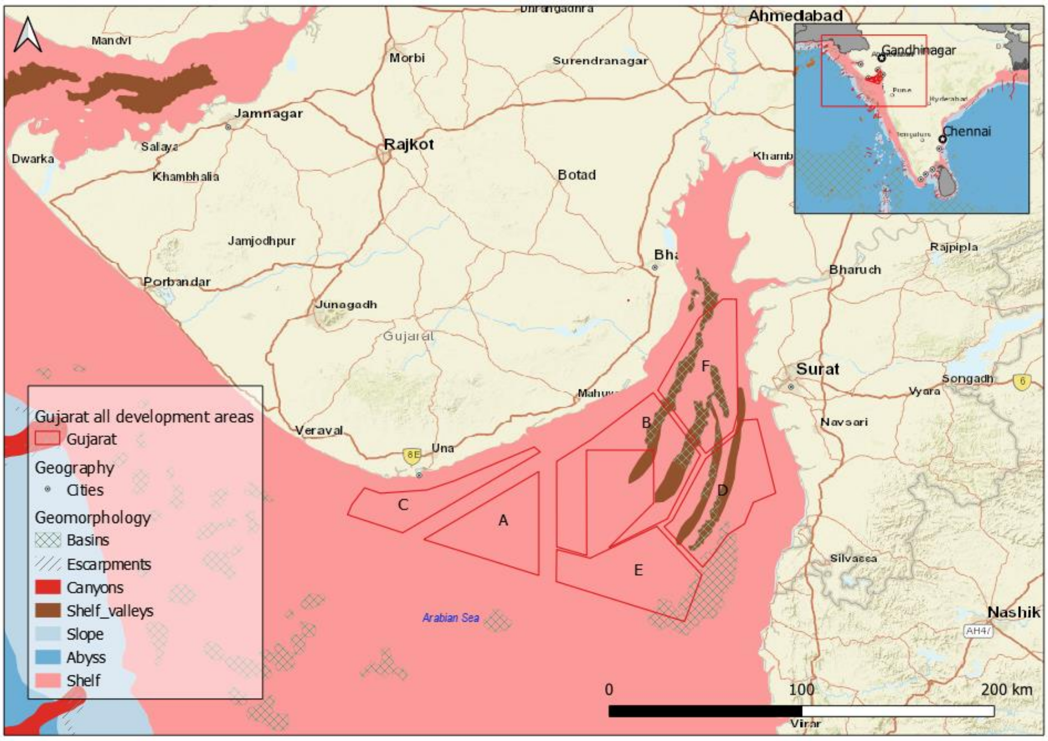

Figure 2.38 - Geomorphology offshore the Gujarat region (Zone A-F marked) (ESRI, 2019)

2.3.4.3 Geology

The Gujarat region is situated on the margin of the Indian craton and located within a relatively tectonically stable area. However, a few major fault lines trending in N-S direction in the eastern part (within the Gulf of Cambay) and in a WSW-ENE direction (within the Arabian Sea in the West and the Gulf of Cambay in the East) have been identified. A large part of the AOI is located within the so-called Surat depression, which has been infilled by various sediments since the Paleocene.

The main land mass of Gujarat is part of the large igneous Deccan Trap formation which composes volcanic extrusions of rock formed about 66 million years ago (mya) at the transition from the Mesozoic and the Cenozoic period. Other rock outcrops in the region are sandstones and siltstones formed about 66-200 mya during the Jurassic and late Cretaceous period. A simplified geological map of the onshore geology with major lineaments and adjacent oil and gas fields are shown in Figure 2.39.

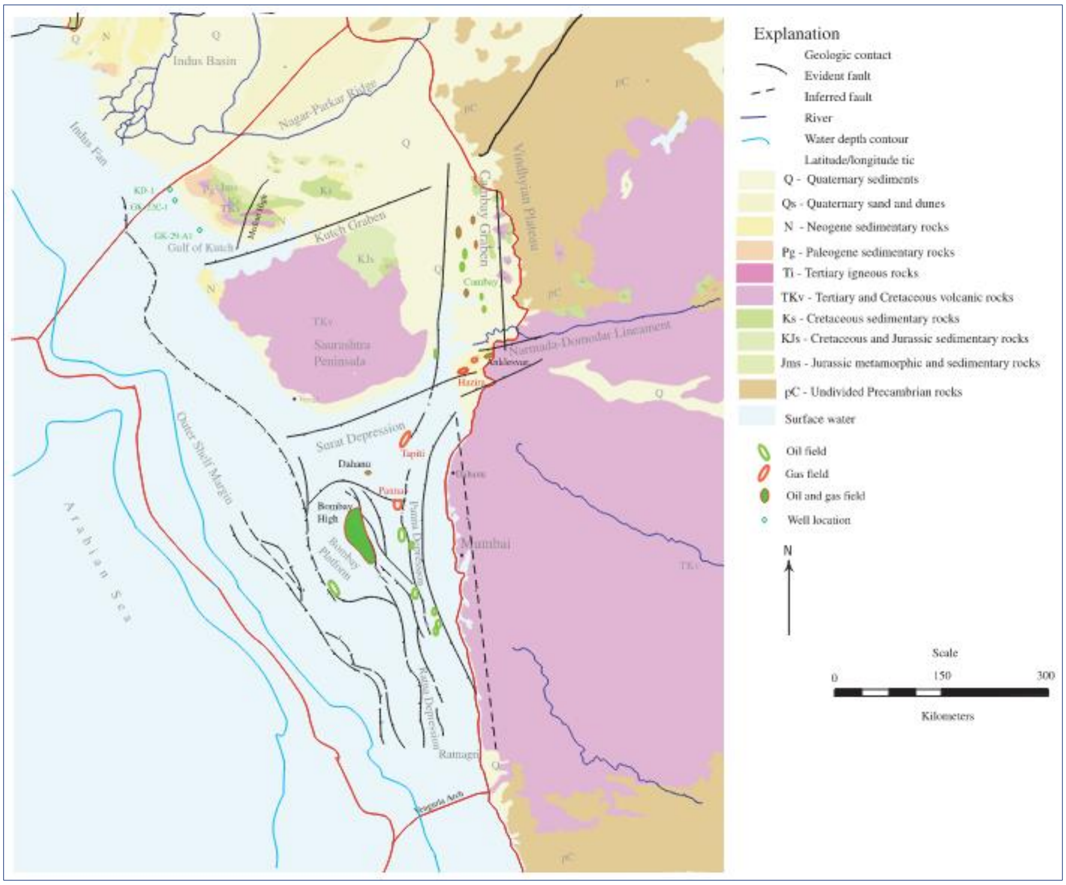

Figure 2.39 - Simplified geological map of Gujarat including major lineaments and position of oil and gas fields in the area (Wandrey, 2004)

The coastal and offshore areas in the southern Gujarat region consist of Quaternary sand, silt and clay deposits. The upper part of the pre-Quaternary sediments consists of thick siliciclastic deposits varying from clay, shale, siltstone, and sandstone overlying the Deccan Trap deposits.

The siliciclastic package deposited during the approximately last 10 my and constitutes an up to 1000 m thick section which is illustrated on the cross section from an area south of the area as can be seen in Figure 2.40.

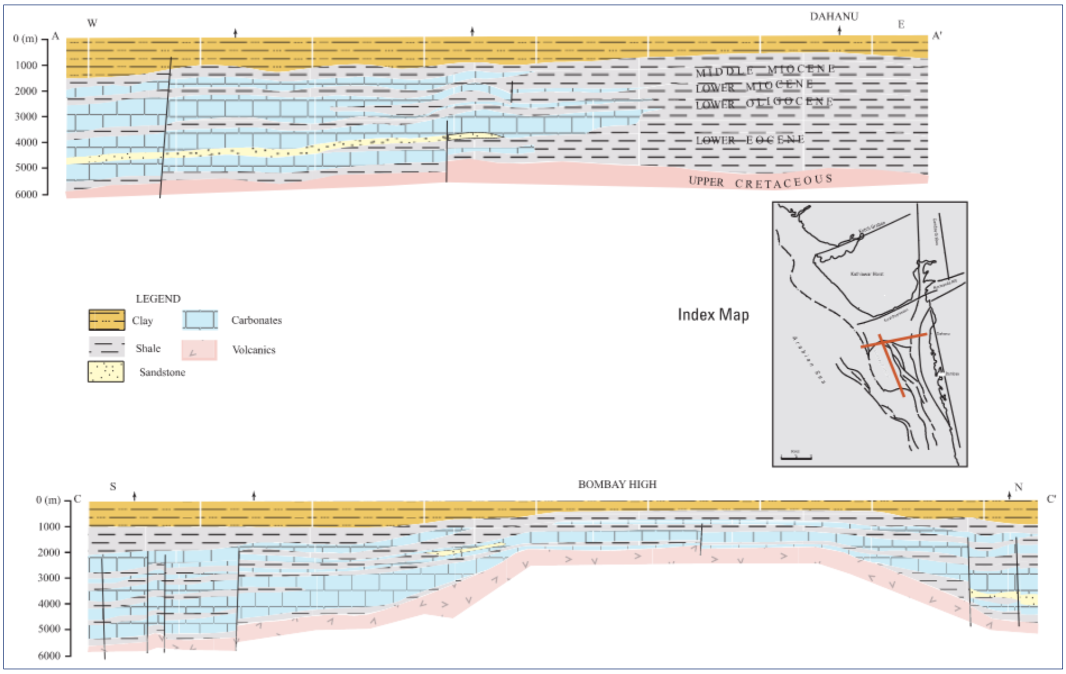

Figure 2.40 - Generalized cross sections offshore Gujarat south of the area. The upper section is W-E oriented, and the lower section is S-N oriented, shown as red lines on the index map. Scale to the left is meters below the seabed (Wandrey, 2004)

For the north-eastern Zones in the Gulf of Cambay (particularly Zone F) the geology might be slightly different, as a survey by the National Institute of Ocean Technology (India) has indicated that the geology in the Gulf of Cambay is comprised of recent sand and clay deposits, permeated by paleo-channels. Both the sandy and shaly formations are believed to be relatively thin with sandstone as the underlying bedrock.

2.3.4.4 Geotechnical

Based on a 2015 Pre-feasibility Study (FOWPI, 2015) and 2018 Pre-Feasibility Study (FOWIND, 2018), an experience based Geotechnical zone description for the Gujarat offshore region has been developed. Below are summarized the indications from the study for each zone.

Zone A is believed to generally comprise of a superficial clay layer followed by interlayered sand and clay strata. The thickness of the superficial clay layer ranges from 20 to 40m increasing towards the south-east with shear strength in the layer increasing as a function of depth varying from soft at the seabed to firm at the interface with the sand layer. The interlayered sand and clay strata are expected to extend to depths of around 120m below the seabed with sand relative densities expected to range from medium dense to very dense.

Zone B is believed to generally comprise of a clay stratum overlying sand. The thickness of the superficial cohesive soil is believed to range between 10-35m increasing towards the south-east with shear strength in the layer increasing as a function of depth from very soft at the seabed to firm at the interface with the sand layer. The sand layer is expected to extend to depths of around 50m below the seabed with relative densities expected to range from medium dense to very dense.

Zone C is believed to predominantly comprise of clay to a depth of around 45m below seabed with occasional laminations of sand below 20m. The shear strength of the clay is expected to be very soft at the seabed becoming firm increasing with depth. The interbedded sand layers are expected to have relative densities in the medium dense to dense range.

Zone D is believed to generally be dominated by medium dense to very dense sand extending to depths of around 40m below seabed. Occasional very soft to soft clays are found at the seabed however the extent of these superficial clay layers is limited to approximately 7m below seabed.

Zone E is believed to generally comprise of a clay stratum overlying sand. The thickness of the superficial cohesive soil is believed to range between 7-25m below seabed increasing towards the northern and westerns extent of the site with shear strength in the layer increasing as a function of depth from very soft at the seabed to firm at the interface with the sand layer. The sand is expected to extend to depths of around 40m below seabed with relative densities expected to range from medium dense to very dense.

Zone F is believed to generally comprise of a sand stratum overlying clay. The thickness of the superficial cohesionless soil is believed to range between 10-50m below seabed increasing towards the northern extent of the site with relative densities ranging from loose to very dense and occasional cemented laminations. The clay is expected to extend to depths of around 125m below seabed with shear strengths expected to range stiff to very hard.

An indicative lower/upper bound soil profiles for Zone A has also been provided. The soil profile shall only be considered broadly representative for the offshore ground conditions in Zone A. The lower/upper bound has been provided to estimate a "Rochdale Envelope" of soil conditions for the zone and as such provided a range of possible conditions or foundation concept comparisons.

The Indicative lower bound soil profile for Zone A indicate clay from 0-40 m and sand from 40-60 m below seabed. The indicative upper bound soil profile for Zone A indicate clay from 0-15 m and sand from 15-60 m below seabed. This indicative, that clay may be present as deep as 40 meters below seabed and that sand may be present up to 15 meters below seabed. The shear strength varies from 5-50 kPa in the clay, with the highest shear strength present in the thickest clay interval.

The estimated soil profiles are considered "weak" when compared with "typical" North Sea conditions. The clay layer which extends to 40m below seabed in the lower bound profile can be described as "very soft". A key strength parameter for clay soils is the “undrained shear strength” (Su) and in Northern Europe values of 200-400 kPa might be seen versus Gujarat’s projected range of 30-50 kPa.

The clay layer will provide limited lateral support to foundation of monopiles and would likely preclude the use of gravity-based structures in Gujarat. The deeper sand layer would provide more support to piles compared with the weak clay layer. Due to these under-consolidated soil parameters, it is anticipated foundation design will be challenging and resulting in higher CAPEX values compared with those seen in Northern Europe. Valuable lessons and best practice methodologies could be obtained in other regions with similar unconsolidated ground conditions.

Based on internal confidential data and in-house COWI knowledge, the subsoil conditions near the eastern part of Zone C and northern part of Zone A may be classified as:

- Very soft to firm silty clay or clayey silty sand seabed to approx. 10 m below seabed
- Very soft to firm silty clay / clayey silty sand or very dense silty sand in the range of 10-20 m below seabed
- Very dense silty sand from approx. 20-30 m below seabed

This is illustrated in Figure 2.41. However, a high degree of local variations of the sediment distribution, sediment strength and sediment thickness are to be expected and the illustration cannot be taken as a general model for Zone A and Zone C. A technical measurement in the upper part of the stratigraphy indicate a shear strength of 5.4 kPa in the clay at a depth of 3.5 below the seabed.

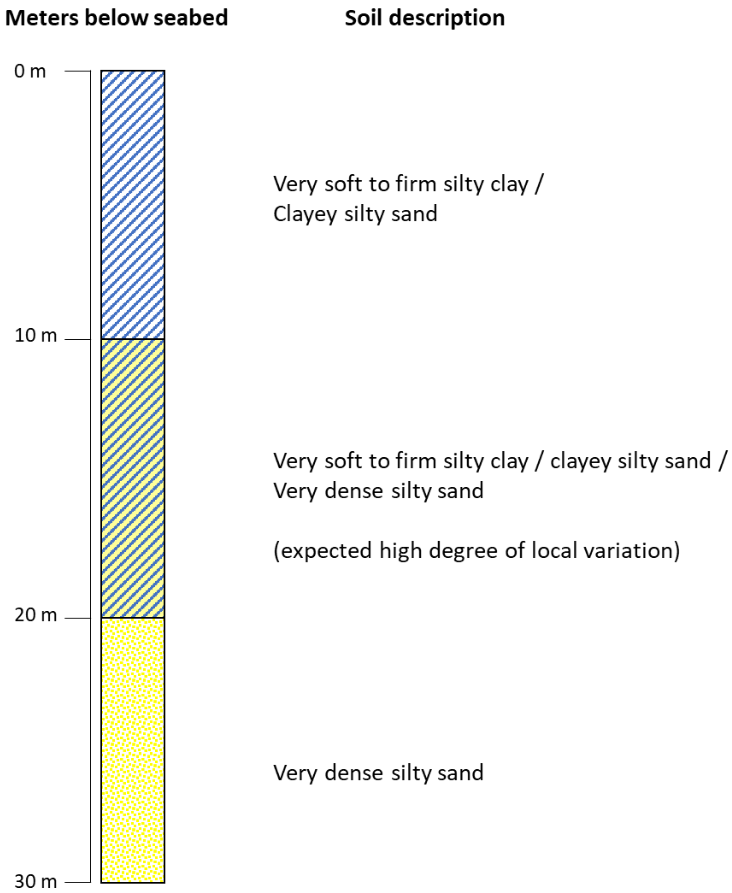

Figure 2.41 - Illustration of stratigraphic profile of what might be expected within parts of the Zone A and C. Note this is a general illustration which cannot be used to plan for foundations, as there will be local variations that are not known at this stage.

Additionally seismic data obtained near the eastern part of Zone C and northern part Zone A indicates clayey silty sand from 10-15 m below seabed and dense silty sand down to approximately 40 m below seabed. Below the dense silty sand are interpreted dense to very dense sand to approximately 80 m below seabed. The seismic data indicates buried paleo-channels from approximately 25 m below seabed down to deeper levels.

It is worth noticing that the potential buried paleo-channels, may contain softer sediment infill in the otherwise dense sand layers. Obtaining new seismic data can help to disclose these potential paleo-channels, which can be a risk for offshore structures.

The data only gives a snapshot of the expected sediments below the seabed and cannot be used as a general model and assumption for the area, as there are too few data points. Variations in the expected sediment type and stratigraphic thickness must be expected, as the indicative lower bound soil profile for Zone A (from geotechnical study) for example indicates clay sections from 15- 40 m below seabed, whereas the internal data (at one specific site only) indicates more sandy and silty facies in general 10 m below seabed.

However, a mixture of silt, sand and clay can be expected to constitute the sediments immediate below the seabed. A concern is that the clayey sediments may constitute thick intervals below the seabed and contain low strength parameters at great depths. Whether the clay has low strength parameters must rely on data from future detailed geotechnical survey programs, obtaining more precise data to estimate the soil parameters. Collection of geophysical and geotechnical data can be combined to generate a ground model to capture spatial variability and geo-hazards across the whole area.

2.3.4.5 Seismicity

In relation to seismicity the onshore Gujarat region has earthquake hazards of different levels from moderate (Zone III) to very high risk (Zone V). However, the high risk and very high-risk zones (IV-V) are in the northern part of the region far away from the area of interest. The onshore areas surrounding the Gujarat offshore area are in the moderate risk zone (III), see Figure 2.42.

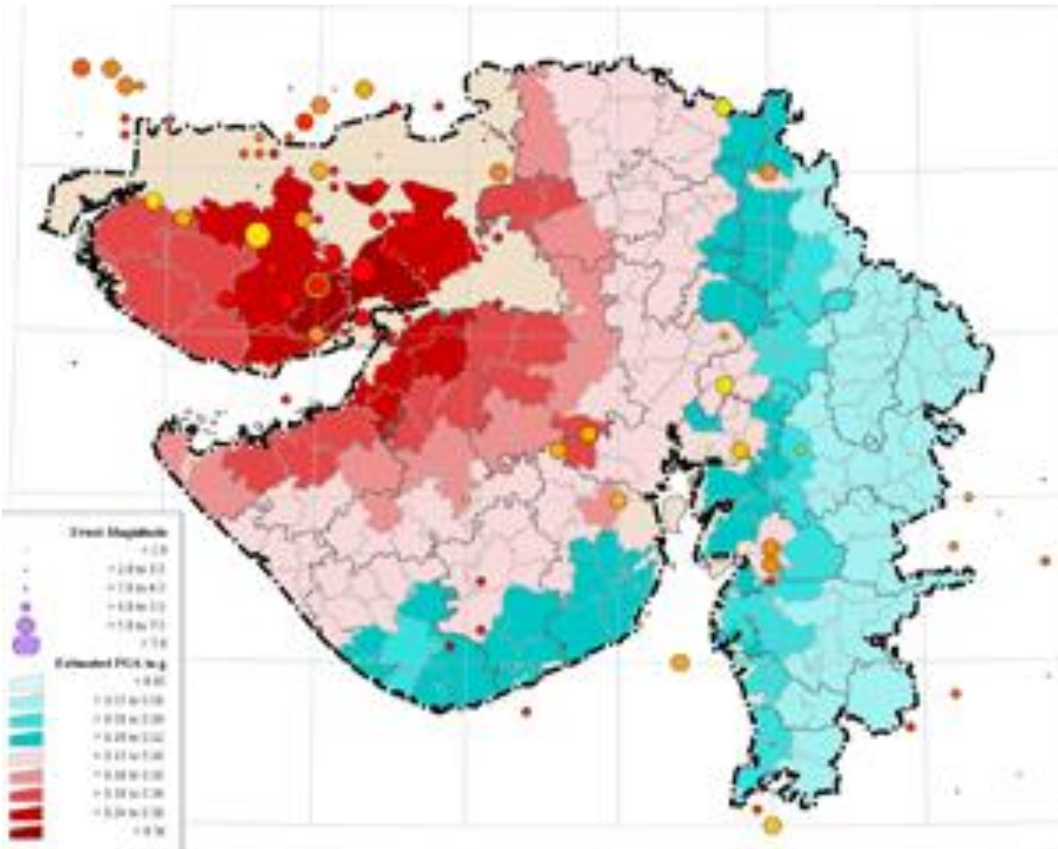

Figure 2.42 - Earthquake hazard risk zonation of the seismotectonic features of the Gujarat region (red = high, blue=moderate intensity): Earthquake | (GSDMA, 2022)

In the last 200 years only two large earthquakes (in 1935 and 1993) were recorded offshore within the area of interest which measured 5.7 and 6.4, respectively, on the Richter scale. Most of the earthquakes in the Gujarat area have the epicenter located onshore (Figure 2.43). The area is considered to be located in the moderate risk zone for seismicity, with the vast majority of the registered earthquakes taking place further north in the Gujarat region.

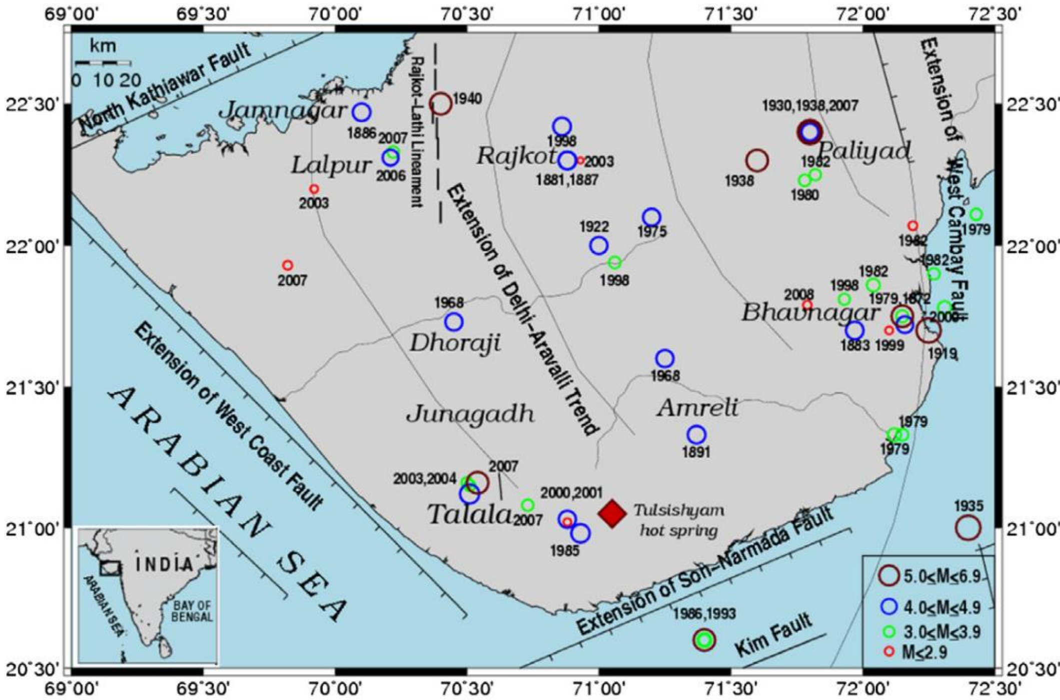

Figure 2.43 - Earthquake distribution in the Saurashtra region of Gujarat within the last 200 years along with major faults (Yadav et al. 2011).

The most significant seismic hazard for the Gujarat area is ground shaking, rather than tsunami risk that apply to other offshore areas (e.g., Tamil Nadu). It is anticipated that foundation design within the Gujarat region will need to require a seismic analysis, liquefaction investigations and analysis of other earthquake hazards.

In relation to engineering risk for foundation types in a seismic area, the general risks can be listed for monopile and jacket foundations.

Monopile foundation risk:

- High moment demand on foundations due to inertia loading + emergency braking (if any)
- Kinematic moments in layered soils
- Loss of lateral load / moment carrying capacity due to seabed liquefaction

Jacket foundation risk:

- Possible buckling of braces

- Stiff system can lead to high rotor nacelle assembly (RNA) acceleration
- Smaller diameter piles (as opposed to monopile foundation) are prone to buckling instability and P-delta effects.

A recent seismic hazard analysis for the Gujarat area has been undertaken. A model for the distribution of peak ground acceleration (PGA) obtained for a return period of 475 years (corresponding to a probability of exceedance of 10% in 50 years) is shown in Figure 2.44. The peak ground acceleration was used to calculate the design response spectra according to the procedures prescribed by the Indian building code (IS 1893 Part 1, 2016).

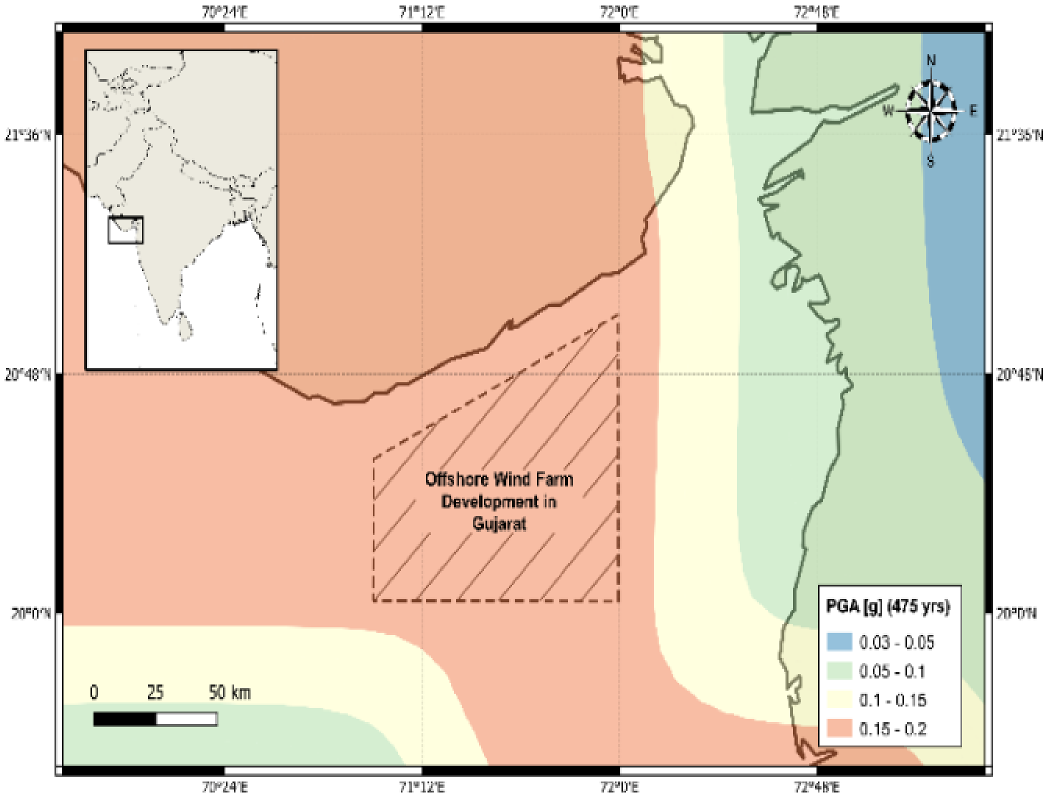

Figure 2.44 - Seismic hazard map for 475 years return period for Gujarat (Bhattacharya et al. 2021)

Note that the area marked in Figure 2.44 as OWF development in Gujarat does not completely correspond to the area of interest in this screening. However, it is worth noticing that the western part of the area of interest is positioned within an area modelled as high PGA values compared to the eastern part.

2.3.4.6 Conclusion

Based on the available data and literature, a high-level review of the seabed conditions offshore Gujarat have been assessed for different geological and geotechnical conditions relevant for construction and operation of OWF such as water depth, seabed sediments, and seismic activity.

In general, the water depth does not exceed 50 m within the area of interest, which favor fixed bottom wind turbines that are economically feasible at water depths up to approximately 65 m. However, as the seabed sediment is likely to consist of loose sediment, e.g., clay with low strength, the gravity-based foundation may not be suitable. The strength in the clay is also of vital importance for monopile foundation, which may also be problematic. Jacket foundation may be of use in the deeper parts of the area of interest, but will also depend on the soil strength parameters. The water depth is generally too low for considering floating foundations.

A general recommendation is to obtain detailed site specific geophysical and geotechnical data to support the further phases of developing the potential Offshore Wind farm areas. These surveys will provide knowledge of the seabed and sub-seabed conditions and structures. A magnetometer survey is recommended to be part of the geophysical survey campaign as the magnetometer survey can identify manmade magnetic objects on the seabed and near sub-seabed. If there is a potential risk for encountering large magnetic anomalies, a UXO survey is recommend. This is to locate potential unexploded ordnance (UXO).

Other important surveys to be acquired is a shallow geotechnical coring and CPT campaign. These campaigns will obtain knowledge related to the sediment distribution, soil parameters and strength conditions in the near subsurface and subsurface sediments. This will greatly improve the understanding of the area for OWF development and help ranking the areas.

Geophysical and geotechnical data will also be important to identify sub-seabed features e.g., paleo-channels, delineations of basins and shelf valleys in the area and will also be of use to identify the stability risks of these areas. A 2D ultra-high resolution multichannel seismic survey can help to locate and trace the position of the paleochannels and identify other sub-seabed structures which can be a geohazard and pose a risk to an OWF development.

Due to the great variation in water depth within the area of interest, it is recommended to collect detailed bathymetric data (e.g., Multibeam Echosounder data) for planning of the design and for placement of the WTG. Also, to identify the seabed features and the risk for seabed mobility.

Earthquakes are a risk in the area of interest. The area is considered a seismic moderate hazard area (Zone III) and there are a few major fault lines crossing the area. The fault lines can influence the seabed stability and therefore further investigations for faults are advised.

It is also important to perform a grab sampling campaign to be able to assess the potential seabed mobility because the movement of seabed sediment can influence offshore installations. Further, it will be crucial to acquire Metocean data in order to obtain knowledge of sea currents in the area of interest. Metocean data can also support a seabed mobility risk assessment.

The seabed offshore Gujarat is believed to consists mainly of clay, silt, and sand. Whether the upper layers of the subsurface is consolidated and to which degree is not known in detail at this stage. The geophysical and geotechnical surveys mentioned above are essential for further screening and development of the project area.

2.3.5 Ports and Logistical Infrastructure

The offshore wind farm supply chain is inseparable from port infrastructure and operations due to the very fact that access to the wind farm location must be facilitated by seafaring vessels. Moreover, as the offshore wind industry matures, the role of ports is continuously evolving. This role is shaped by markets which dynamically price the availability of facilities, vessels, components, weather windows and distances between different sites of interest.

Construction ports for fixed-bottom foundations are an essential enabler for wind farm construction and can act as a key constraint. Operation and maintenance ports have much lower technical requirements than construction ports. Their location should be as close to the wind farm they serve as possible, but this is not usually a bottleneck, as a small regional or even local port / fishing harbour can potentially be used with minor adaptations.

2.3.5.1 Construction Port

The rough screening (refer Section 2.2.4.10) identified Pipavav and Hazira Ports as potential candidate construction ports closest to the offshore windfarm development area in the considered OWF zone B3.

The distance from the ports to the OWF zone and the location of the ports can be seen below in Figure 2.45:

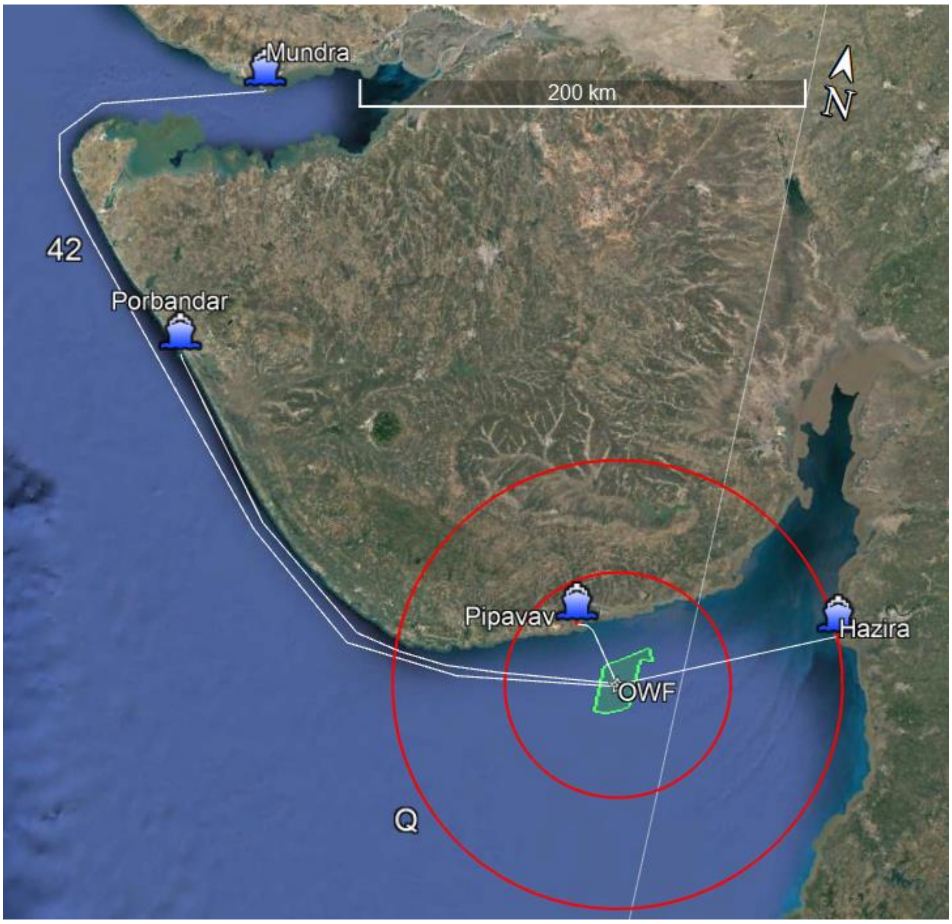

Figure 2.45- Distance to ports from OWF zone B-3 zones (COWI, 2022)

Water depths extracted from Navionics and satellite photos from Google Earth can be seen in Figure 2.46 and Figure 2.47.

Figure 2.46 - Pipavav Port water depth and satellite photo zones (COWI, 2022)

Figure 2.47 - Hazira Port water depth and satellite photo zones (COWI, 2022)

2.3.5.2 Operation & Maintenance (O&M) Ports

OWF in operation requires regular maintenance to minimize downtime and maximize the generation of electricity. These activities include (but not limited to):

- Management of the asset: remote monitoring, environmental monitoring, el. sales, administration etc.
- Preventive maintenance: routine inspections, change of lubrication oils and preventive repair of parts known to wear down over time
- Corrective maintenance: repair or replacement of failed or damaged components

O&M strategy differs from one operator (OEM) to the next aiming to find the optimal intersection of access to the asset and onshore support:

- Access to the asset: transit time and the period in which a turbine can be reached by particular means
- Onshore support: availability of parts and services taking part in maintenance or repair

While the development of O&M infrastructure represents a small portion of the initial offshore wind capital investment, over the long-term (typical lifetime of 25 years), O&M will make up a large proportion of the overall cost of energy. Operating expenses can comprise up to 30-40% of the LCOE (BVG Associates, 2014) and (International Renewable Energy Agency (IRENA), 2018). Hence, early planning of O&M strategies and identification of suitable O&M infrastructure can make a significant difference to a project's economic viability.

Although O&M ports must satisfy technical requirements, discussions with developers are mostly commercial. Another factor is the strategic commitment of the port to support these operations as it lasts throughout the lifecycle. (LEANWIND, 2015).

O&M base ports can be quite different from the installation ports, as their main requirement is proximity to the farm and as infrastructure requirements are less demanding compared to installation.

Note that for potential O&M Ports, the requirements as listed above for the Transport and Installation Base Port are similar but significantly less stringent. Access is of course still required, but typically only for a Crew Transfer Vessel (CTV). In the case of the development of further windfarms, then the decision should be taken to develop also an O&M Hub, with more advanced facilities, especially in the rare occurrence of Blade or Nacelle replacement activities. This would require similar berthing and lifting facilities as the Transport and Installation Base Port.

The requirements and a gap analysis is currently being identified in a study initiated by the Danish Energy Agency together with MNRE and NIWE. This port study will provide further clarity regarding this topic with a detailed assessment of viable ports to serve offshore wind projects located off the coasts of Gujarat against pre-defined baseline criteria for a construction port and an O&M port.

2.3.5.3 Conclusion and Next Steps

The rough screening and a preliminary assessment of ports around the shortlisted OWF site in Gujarat based on open source, confirms that there are potential candidate ports that could potentially support construction and installation of OWFs at the shortlisted site. However, further assessment is needed to be carried out for unknown parameters.

A more thorough analysis is being carried out as mentioned above on ports by the Danish Energy Agency where bottlenecks as well as hard constraints along with indicative investment costs are identified. The output of that study will hopefully give a clearer picture of the ports in the Gujarat region for both installation and O&M operations.

2.3.6 Heat Mapping Based on LCoE

A traffic light map for data representing exclusion and restriction zones as well as no-go areas incorporating all the considerations during rough screening has been created as a summary of the assessment in Figure 2.25. It has been concluded that further analysis will be considered for the areas classified with green and yellow colors in order to be able to select the best areas for offshore wind development.

Additional considerations, assessments and constraints have been introduced during the fine screening process with potential benefits and risks being identified on the classified areas. As a result of this process and before setting the conceptual planning basis for the buildout plan, a heat map is created based on LCoE values calculated in the area as can be seen in Figure 2.48. This step is necessary in transforming all the gathered information into a quantitative scale that can be used as an economic parameter to select the area with best conditions for offshore wind development. A more detailed description of the methodology for calculation of LCoE can be found in Appendix A: GIS guide combined with the description of methodology of rough and fine screening.

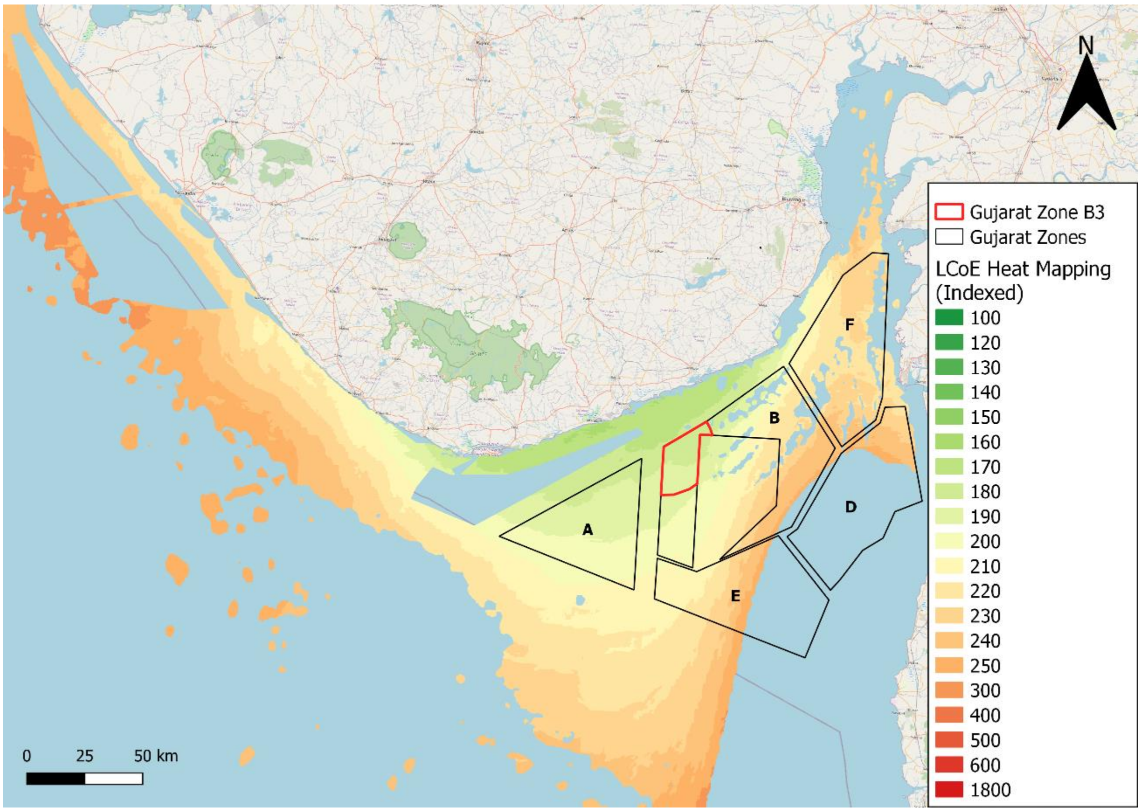

Figure 2.48 – LCoE Heat Map of Gujarat coast

From the above figure it can be seen that large portions of zones D and E are taken out from the LCoE mapping due to wind speed considerations. Zones C, G and H are excluded from the mapping due to areas not being clarified by MoD. Offshore wind zones A and B are the most attractive sites from an economic and Levelized Cost of Electricity point of view.

2.3.7 Conceptual Planning Basis

The conceptual basis elements such as energy density and area requirements, module size considerations, electric power connections and export configurations as well as external wake losses and distances between wind farms are explained in the Maritime Spatial Planning report for Tamil Nadu in detail, and these similarly would be relevant to Gujarat. Therefore please refer to the Tamil Nadu report for a detailed explanation of the elements related to the Conceptual Planning Basis (CoE, 2022).

The most significant difference in terms of conceptual planning basis between Tamil Nadu and Gujarat OWF zones can be the turbine suitability assessment. Due to differences in wind profiles between the two regions, a turbine type that is more suitable to lower wind speeds might be a better choice for offshore wind projects in Gujarat coast.

A hypothetical turbine type suitable for lower wind speeds with a nameplate capacity of 10MW and a rotor diameter of 220m has been assessed to be producing higher AEP in comparison to higher capacity turbines in a business case carried out in FIMOI project. (CoE, FIMOI version 2, 2022) However, the comparison of the business cases contain other parameters that might have impact on the results so this observation should be taken only as an indicative finding. A more detailed study should be carried out to determine the optimum turbine type for the wind climate in the region.

2.4 Results

2.4.1 Conceptual plan and build-out considerations

This section presents the conceptual plan for proposed sites within Gujarat OWF zones and input regarding buildout considerations based on the rough and fine screening exercise, heat mapping and conceptual planning basis.

In relation to the conceptual plan and proposed buildout plan the key considerations are related to the below parameters:

- Marine Traffic Separation Scheme
- Oil and gas platform and exploration areas
- Energy density and area requirements
- Module size
- External wake losses and distances between wind farm sites
- Grid connection points and electrical configuration

2.4.1.1 Marine Traffic Separation Scheme

Significant traffic appears to originate from the ports off the Gujarat coast passing through the OWF zones, and the marine traffic definitely needs to be considered and further assessed to avoid a potential direct conflict with the planned OWF development. The borders of the various OWF zones have been drawn during the assessment in the prefeasibility report (FOWPI, 2015) with distances between the site borders e.g. to allow for navigational corridors allocated for vessels and boats operational in the area especially between OWF zones A, C, B and E. However, as mentioned during rough and fine screening, the more updated analysis in Figure 2.26 shows that vessel traffic is actually not very consistent with the navigational corridors in the prefeasibility report, and therefore it would be beneficial to carry out a more detailed vessel traffic analysis and assessment in order to reassess the OWF zones and to ensure the most efficient and sustainable co-existence of both marine traffic and offshore wind farms.

2.4.1.2 Oil and gas platforms and exploration areas

Oil and gas pipelines are seen crossing the OWF zones. The zones also lie within and in proximity of oil fields, and there are a number of active and awarded oil and gas blocks overlaying with the zones allocated for offshore wind development off the Gujarat coast. Therefore, further liaison with relevant stakeholders is critical to confirm this assessment and understand the potential constraints.

2.4.1.3 Energy Density and area requirements

The energy density adopted in the conceptual planning influences the overall power generation from any offshore wind areas. Except for the zone B3, where there is carried out both geophysical and geotechnical investigations and a rapid EIA, the understanding of the various risks and constraints is limited and not based on data, information and assessments from surveys and investigations carried out. For that reason, it would be risky to adopt a very high turbine density for planning purposes. Also, there has been no experience in India in relation to offshore wind development. Therefore, as a starting point and based on the experiences in other mature markets a density of 3 -7 MW/km² could be adopted for the initial proposed projects.

While it is normally left to the project developers to adopt a suitable energy density that would deliver most cost-effective power (lowest LCOE), the decision / guidance of Indian Stakeholder, in terms of energy density, would allow harvesting the maximum potential of wind power from this region to also ensure the total accumulated target capacity is reached.

The option of providing flexibility in determining the specific density and actual micro siting would also be considered an important element for the developers to ensure the optimal use of the area.

2.4.1.4 Module size

The current market experience indicates OSS sizes in the range of 500-750 MW as this is a well-developed and proven design, but also see larger OSS and park capacities. It is of course important to consider potential supply chain constraints, which might restrict the size of offshore substations and that larger offshore substations involve significantly more complex design, more excessive weight and more complex inter array cable installation. On the other hand larger offshore substations should be considered also bearing in mind the time perspective from early development to procurement and the general economy of scale, which will favor wind farm capacities of 1.0-1.5 GW. Also the 30 GW target by 2030 and presented indicative trajectory of offshore wind projects represents a future pipeline, volume and scale, which supports a gradual increase in windfarm size - especially as the local supply chain becomes more mature and experienced.

2.4.1.5 External Wake Losses and distances between wind farm sites

Purely from a wake loss perspective, it would be beneficial to have a large distance between wind farm sites. However, such strategy would be detrimental from a societal perspective as this will require large separation distances between the wind farms, implying significantly lower accumulated power generation for future offshore wind projects in Gujarat.

As specified in the MSP report for Tamil Nadu (CoE, 2022), the benefits achieved by maximizing separation distance between windfarms (3-5% reduction in wake losses) cannot justify significant overall reduction of total power output (estimated to be around 20 – 30 %) from the OWF development areas in Gujarat. Therefore, it is recommended not to consider the external wake loss effects in the OWF site conceptual planning and the separation distance (if any) should only consider practical aspects such as access corridor for construction, installation and operation vessels and electrical infrastructure.

As such, there are no further provisions made to reduce / eliminate external wake loss effects except for the required separation to accommodate electrical infrastructure and access corridor. Taking different approaches of various countries, it is reasonable to consider a corridor width of 1 km between the sites, which will be sufficient enough for safety of installation and maintenance activities of export cables. This 1 km corridor width is purely considering the transmission infrastructure and access corridor to ensure optimization of the offshore wind development areas. In this perspective the 1 km corridor width could function as an initial planning assumption bearing in mind that many other risks and constraints would need to be considered and assessed throughout the further development and EIA work before the actual deployment of turbines.

Considering the shorter term goals, a total capacity of 1 GW is planned to be awarded in 2023-2024 in Gujarat which is part of a total auction trajectory for offshore wind in India until 2030 according to the strategy paper released by MNRE in July 2022. This means that it can be possible to award the whole capacity of 1 GW to a single site without any need of consideration for external wake losses. Therefore, it will make more sense to perform wake loss analysis in case higher capacities that can be awarded to neighboring sites are planned in Gujarat in the auction trajectory.

2.4.1.6 Grid connection points and electrical configuration

Rough Screening provided an overview of the electrical national grid showing various substations that are in the vicinity of OWF zones in Gujarat. Initial findings show that the proposed substation in Jafarabad called Pipavav substation appear to be a promising choice for potential connection to the initial wind farm project(s) in Gujarat. According to the Network Planning Report released by GETCO in March-2022 (GETCO, 2022), it is mentioned as a(n) offshore/nearshore pooling substation that can handle the evacuation of 1000 MW capacity as part of the state roadmap for RE capacity addition. The visualization of this substation can be seen in Figure 2.49.

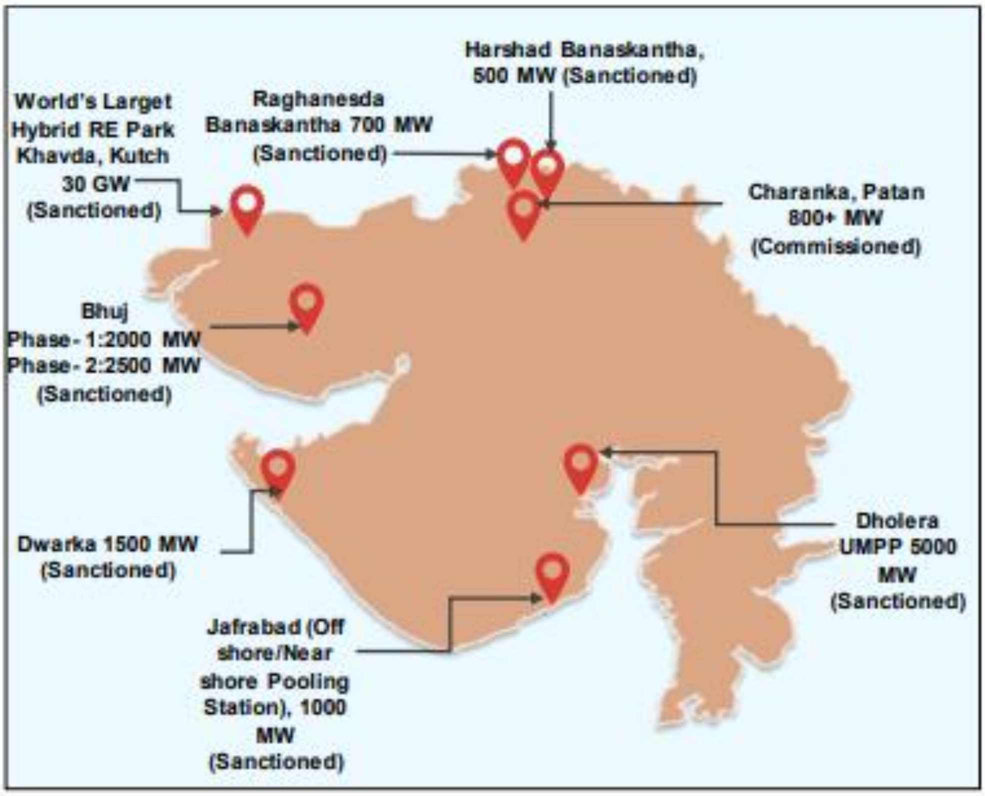

Figure 2.49- State Roadmap for RE Capacity Addition (GETCO, 2022)

The planned schemes for Pipavav substation are also included in the same document for FY 2022 – 2026 & onwards. The details of this plan can be seen below in Table 2.2:

Name of Sub-station (District)	Name of Associated Transmission Elements	Line Length [CKm]	Type of Scheme
400 kV Pipavav (Amreli)	1. 400 kV D/C Pipavav-Amreli line 2. 220 kV D/C Pipavav – Otha line 3. 220 kV D/C Pipavav-Bagasara line	150 50 80 12	System Strengthening

	4. 220 kV D/C Pipavav – Rajula line 5. 400/220 kV, 2 X 500 MVA ICTs 6. 220/66 kV, 2 X 160 MVA ICTs		

Table 2.2- 400 kV Pipavav substation elements planned during FY 2022-2026 & onwards (GETCO, 2022)

2.4.2 Proposed build-out plan

NIWE has carried out the following investigations for 365 km^2 sea bed area of zone B3:

- Lidar-based offshore wind resource assessment for two years
- Geophysical and geotechnical investigations
- Rapid EIA study
- Oceanographic (wave, tide and current)

and as pr. the MNRE strategy paper and the indicative auction trajectory for offshore wind 1 GW of the capacity in the year 2023-24 is planned to be allocated to this zone B3.

Year	Total auction trajectory (GW)
2022-23	4[1]
2023-24	4[2]
2024-25	4
2025-26	5
2026-27	5
2027-28	5
2028-29	5
2029-30	5
Total	**37**

[1] The whole capacity is planned to be allocated to sites in Tamil Nadu, (MNRE, 2022)

[2] 1 GW of this capacity is planned to be allocated to the zone B3 in Gujarat, (MNRE, 2022)

Table 2.3 - Total Auction Trajectory in GW (MNRE, 2022)

The data and information gathered via the various surveys and investigations together with the relevant studies and assessments is of course extremely important as part of the de-risking and further development of the zone B3. Considering the power evacuation, it can also be observed that a 400kV substation is proposed at Pipavav, which is a potential connection point for power generated by offshore wind farms in the region at zone B including zone B3.

Following the focus on zone B3 as the first part of the build-out plan it is important to consider the assessments and considerations made during rough and fine screening, the heat mapping and conceptual planning. Bearing these in mind the most attractive parts off the Gujarat coast would be to the West for the zone B3 into the zone A from LCoE perspective.

Considering the water depths in particular the zone D and parts of zone E and F are within areas with deep water above 65 meter, which is considered the current threshold for fixed-bottom foundations. This means that most of zone D and parts of zones E and F are not assessed to be suitable for fixed-bottom offshore wind turbines.

Especially the constraints related to the oil and gas activities seems challenging to the eastern and southern parts of the zones off the coast of Gujarat – both considering actual oil and gas fields, but also the active and awarded oil and gas blocks, which are overlaying with especially the zones B, E, D and F.

Considering the Ministry of Defence only the following zones: A, B, D, E and F have been given in principle clearance by MoD based on previous communication. Zones C, G and H haven't been given clarification and thus is not suitable for offshore wind farm development.

Considering the environmental aspects and sensitive areas the zones G and H are the most constrained bearing in mind particularly the IMMA and turtle nesting sites. The fact that the Ministry of Defence has not given in-principal clearance for these zones, and the relatively less attractive LCoE level categories the zones G and H as the least suitable zones for development of offshore wind farms.

To summarize, the focus for the build-out plan following the development of zone B and in particular zone B3, would logically be on the areas to the West of zone B to avoid the oil and gas constraints and less economic viable zones from a LCoE and bathymetry perspective. The total area of A is 1,742 km^2 and depending on the density assumed possible this could provide very indicative capacities ranging from 5.2 GW to 12.2 GW using a density of 3 MW/km^2 and 7 MW/km^2 respectively.

Subject to the feedback from the Ministry of Defence it would be relevant to also consider the suitability of the corridor in between zone A and zone C for offshore wind farm development. This corridor if added to zone A can increase the capacity to be allocated in the region. Within this combined area there will remain a number of constraints, and as described the marine traffic in particular would need to be considered and as indicated the previous allocated corridors could potentially benefit from being reassessed to optimize the co-existence between marine traffic and offshore wind.

Many other constraints and risks will need to be assessed and the actual division into specific module size areas and providing areas for the electrical infrastructure will also impact the actual area available for the deployment of offshore wind turbines.

2.4.3 Future perspectives and next steps

MSP is about managing the distribution of human activities in space and time to achieve ecological, economic and social objectives and outcomes. It is a political and social process informed by both the natural and social sciences. Over the last 20 years, MSP has matured from a concept to a practical approach to moving towards sustainable development in the oceans. Integrated marine spatial plans have been implemented by about 20 countries, and it is expected that by 2030, at least a third of the surface area of the world's exclusive economic zones will have government-approved marine spatial plans (Ehler, 2017).

This current assignment to notify the most suitable zones for deployment of offshore wind in India in the state of Gujarat in accordance with the renewable policy and target of 30 GW offshore wind by 2030 is the initial step and process. The MSP process is dynamic and it is important to continue and refine the input and data.

2.4.3.1 Continuous information and data gathering

Within the studied sites, selected environmental and human use parameters were mapped in GIS, to the extent possible, given the information available. The following parameters were mapped:

- Natural environment parameters (protected areas, birds, marine mammals, habitats and fish) and
- Human use features (visual effects, shipping, fisheries, tourism, military grounds, other marine exploitations, cables and pipes and air traffic)

It is considered very important to continuously collect and gather relevant information and data making the marine spatial planning more robust and increase the evidence base for qualified decisions.

As mentioned several time the seabed conditions at the OWF site, has significant influence on the foundation design, turbine layout and therefore associated cost / LCOE. In order to have significant confidence in marine spatial planning outcome, it is imperative that seabed conditions are assessed thoroughly, key geotechnical risk are identified and evaluated. All of the above will obviously have an impact on the build-out plan.

As explained in earlier sections, the current data availability restricts a detailed evaluation of the seabed risks, and besides these risks there are many other aspect that needs to be consulted on as specified below.

2.4.3.2 Co-existence and consultations with relevant stakeholders

The overall objective of Marine Spatial Planning is to address spatial conflicts amongst various stakeholders and allow mutual coexistence of various interest groups. The information and data gathering will illustrate and qualify the potential constraints and conflicts, but to attain the objective of the marine spatial planning, it is also extremely important to conduct consultations with relevant stakeholders and obtain regular feedback on planning proposals for realignment and refinement of proposed development plan. Addressing spatial conflicts is considered as the key to attain transition from theoretical to actual offshore wind projects.

To this end, it is highly recommended that focused consultations are carried out with various parties for de-conflicting the offshore wind farm development in Gujarat:

Oil and gas activities: Oil and gas pipelines are crossing the OWF zones. The zones also lie within and in proximity of oil fields, and there are a number of active and awarded oil and gas blocks overlaying with the zones allocated for offshore wind development off the Gujarat coast. Therefore, further liaison with relevant stakeholders is critical to confirm this assessment, understand the potential constraints and discuss the opportunities of co-existence.

Shipping: It is suggested that extensive consultation is carried out with Ministry of Ports, Shipping and Waterways (MoPSW) and other stakeholders (Shipping corporations and association) to obtain feedback on the proposed traffic management planning and potential reassessment of separation schemes.

Transmission Grid and electrical system: The available information in public domain only allows for a high-level screening of available grid connections and rated capacities of potential point of interconnection (substations). In relation to the initial build-out and focus on zone B3 the proposed substation in Jafarabad called Pipavav substation appear to be a promising choice for potential connection and evacuation of the wind power. But for the longer term and the further evacuation of wind power the close liaison with Transmission System Operators (CTU, PowerGrid and Gujarat Electrical Transmission Company (GETCO)) is essential to fully understand the impact on grid due to power connection by OWF and evaluate / consider options for reinforcement of the Grid.

Environment: the available environmental data relevant to the project site is quite limited, therefore it is recommended that relevant stakeholders such and Ministry of environment, forest and Climate Change, Department of Environment (Government of Gujarat) and other environmental institutions are consulted to further understand/ evaluate potential conflicts and concerns.

Fisheries: The analysis established that the areas of the coast of Gujarat is highly productive for fishing. To this end further liaison with relevant government ministry and fishermen cooperation(s) is strongly recommended to fully understand the constraints and allow for planning for co-existence of offshore wind and fishing activities.

Defence: Although it is understood that Ministry of Defence has previously been consulted with during finalisation of OWF zones in Gujarat, considering dynamic and evolving nature of defence requirements it is recommend that a close liaison is maintained with relevant authorities to understand potential constrains / conflict with OWF planning.

As mentioned throughout the report, it is very important to continuously maintain and extend the engagement and dialogue with the relevant stakeholders.

As is the case in other markets it might make sense to establish a certain governance and structure for the engagement between the relevant parties. As illustrated below there is a certain governance and structure established for the regular maritime spatial plan and coordination for the activities within the Danish territorial waters. As specified in Figure 2.50, there are both representation of the political level with ministries and the operational level with the various agencies.

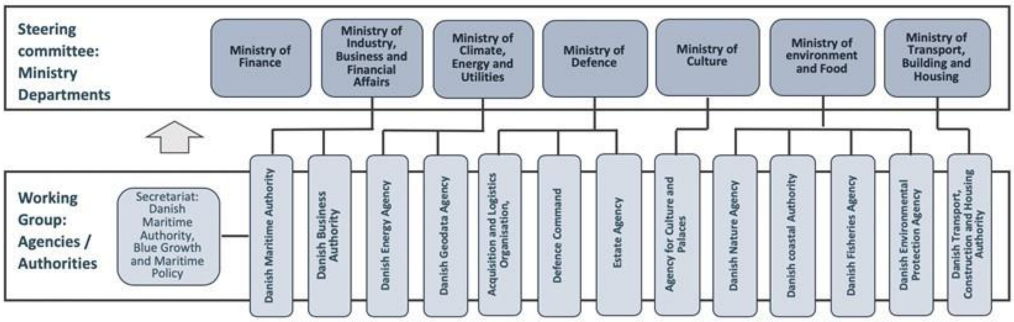

Figure 2.50 - Governance structure for MSP

Similarly a proposed Indian maritime spatial planning committee could be established consisting of various institutional stakeholders to ensure the continuous dialogue and engagement across the various sectors and further guide the MSP process. An example of the structure of such a committee can be seen in Figure 2.51.

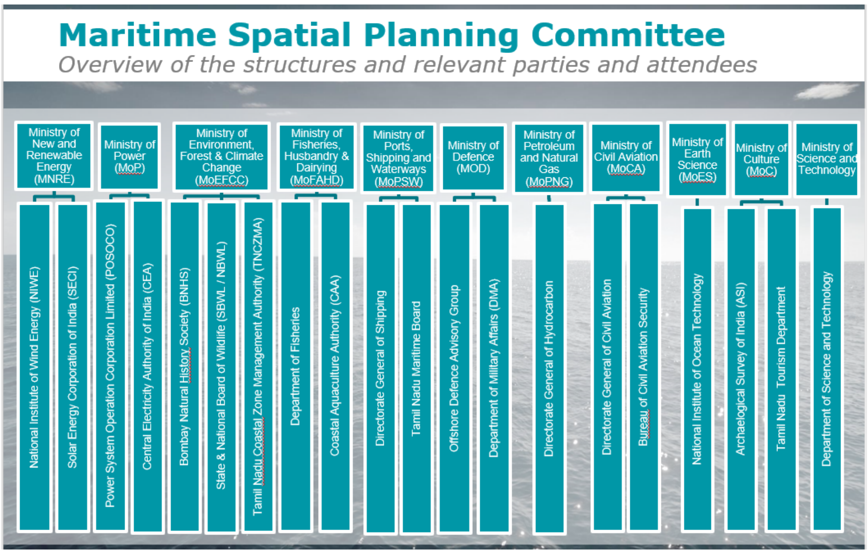

Figure 2.51 – Proposed Maritime Spatial Planning Committee

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Appendix

Appendix A. GIS Guide and Description of Methodology for LCoE Calculation

Appendix B. Concept and System Description of an Offshore Wind Farm

Appendix A:

GIS Guide: Determining Offshore Wind Farms in India

14 February 2023

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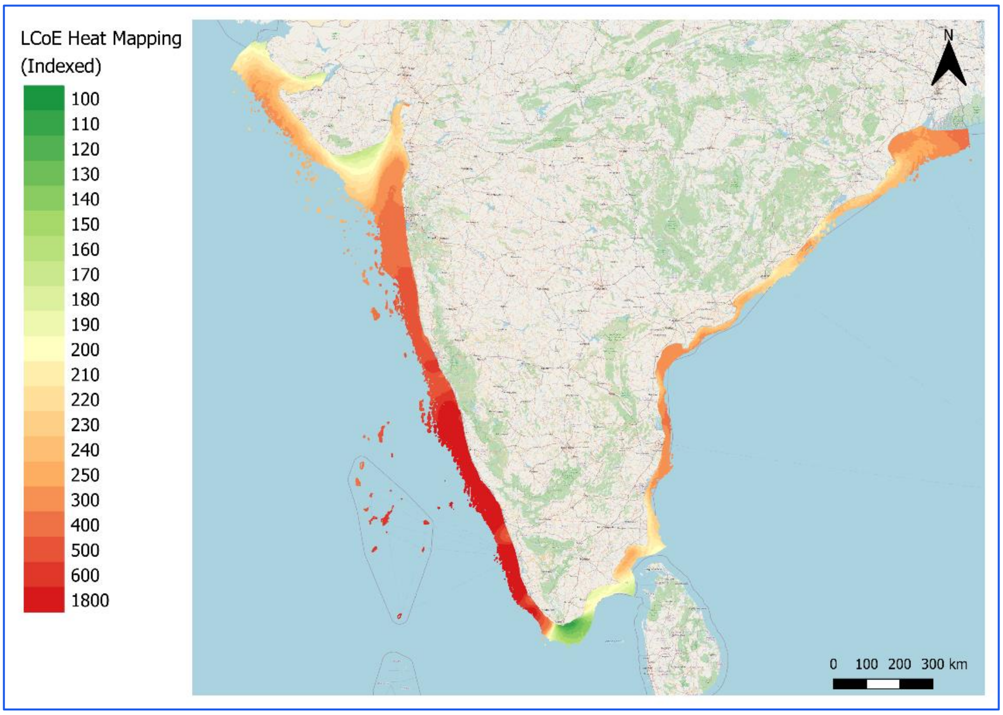
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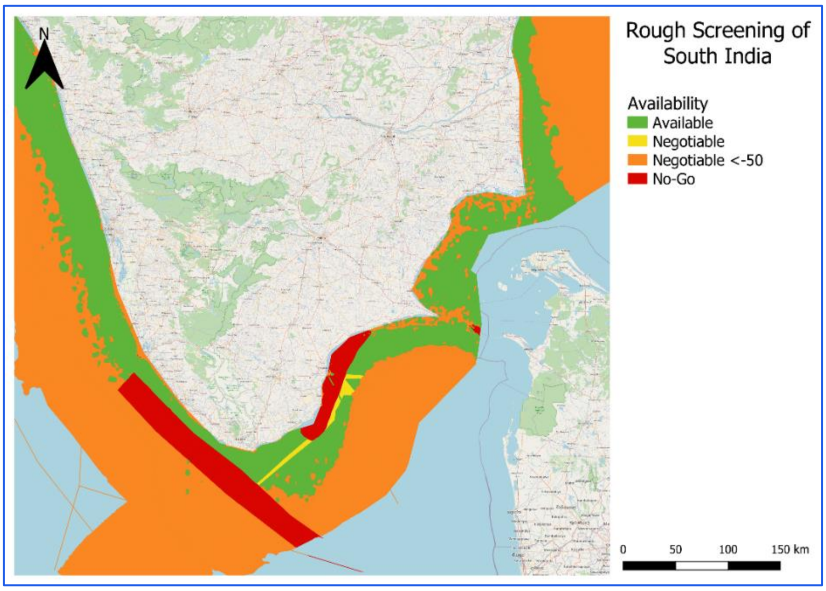
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1. Introduction

This guide was created for beginner and intermediate QGIS users. Therefore, some experience with geographic information systems (ArcMap, AcMap Pro or QGIS) is of advantage in order to follow this guide.

Throughout three focus areas the usage of QGIS to perform screening exercises is exemplified. These screening exercises are commonly applied in Denmark to determine suitable areas for the implementation of offshore wind farms.

Focus Area 1	Example on How to Create a Weighted Heat Map	This mapping exercise produces a heat map that serves as an indicator for **feasible** areas for offshore wind. The heat map is produced based on bathymetry and wind speed data.
Focus Area 2	Example on how to calculate Levelized Cost of Energy (LCoE) of the Indian offshore area using QGIS.	This mapping exercise contains a few central steps in QGIS, thereafter the LCoE is calculated using Excel.
Focus Area 3	Example on How to Perform a Rough Screening for Suitable Sites for Offshore Wind Farms	This mapping exercise produces one data set that includes all relevant information on the availability of the offshore area and thus highlights **suitable** areas for offshore wind farming.

Please note that the exercises are documented for learning purposes only. Accordingly, the results are based on the current knowledge that is subject to change as the project evolves and more data is discovered. Consequently, when carrying out the exercise with a different set of data, the outcome will be different.

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With further questions or in need of support regarding the execution of the exercises, please contact Hans Lyhne Borg (hlbg@ens.dk) or Nele Paulsen (nlpl@ens.dk).

Software

The guide has been prepared using *QGIS Desktop 3.16.11.*

2. Focus area 1 – Producing a Heat Map (Weighted)

A heat map is a data visualization technique that shows the magnitude of an occurrence through color. The map is typically produced using one or multiple **raster layers**. When multiple occurrences 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 simple and dimensionless values (e.g. 1-100). This re-classification of the data enables to summate two or more dimensions (m/s, m, m^2).

In our case, we want to visualize the areas with the highest wind speed and the lowest water depth in order to determine the most feasible areas for offshore wind farming. To do so, we need to combine the spatial information on wind speed (m/s) and water depth (m) by assigning both data new dimensionless values by using a **raster analysis tool: reclassify by table**. Afterwards, the reclassified data are combined using the **raster calculator tool**.

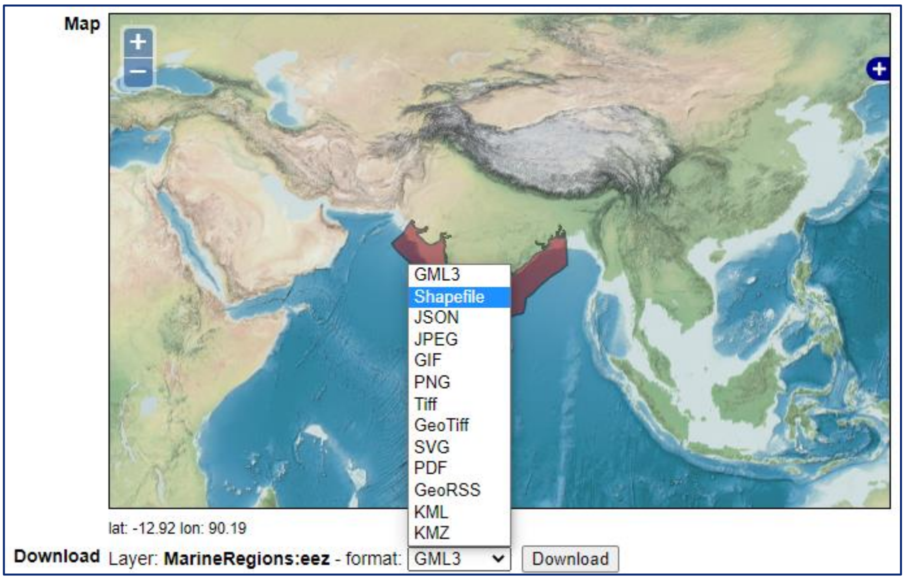
2.1 Step 1. Clip Your Data to a Mask Layer

The first step is to **clip** the wind speed data to the extend we want to work in. It is always useful to confine your work to specific areas, as it saves you a lot of processing time. Further, this step makes working with different layers much easier.

You may use a shapefile of the Indian Exclusive Economic Zone (EEZ) as your **mask layer**. Download the layer using the following link:

https://marineregions.org/gazetteer.php?p=details&id=8480

On the website, choose *Shapefile* as your format.



After finding your clipping layer go to **Raster → Extraction → Clip by mask layer**

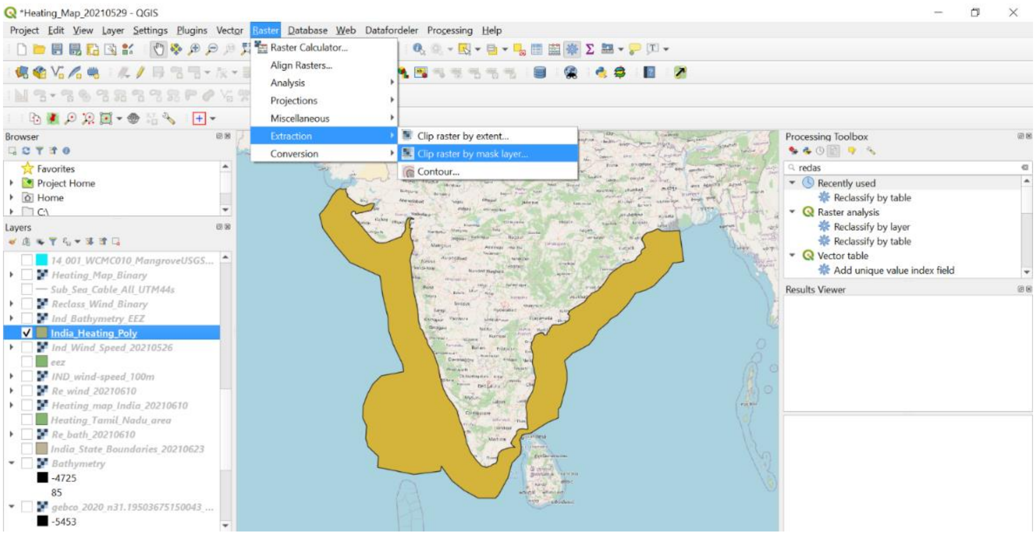


Figure 1: Clip by Mask Layer

Choose the wind speed raster layer as your **input layer**. Choose the Indian offshore area to be your **mask layer**, see figure 1.2. Before you click run, make sure to save the output file to a folder (see Figure 1.3). When you have saved your output file, click **run**.

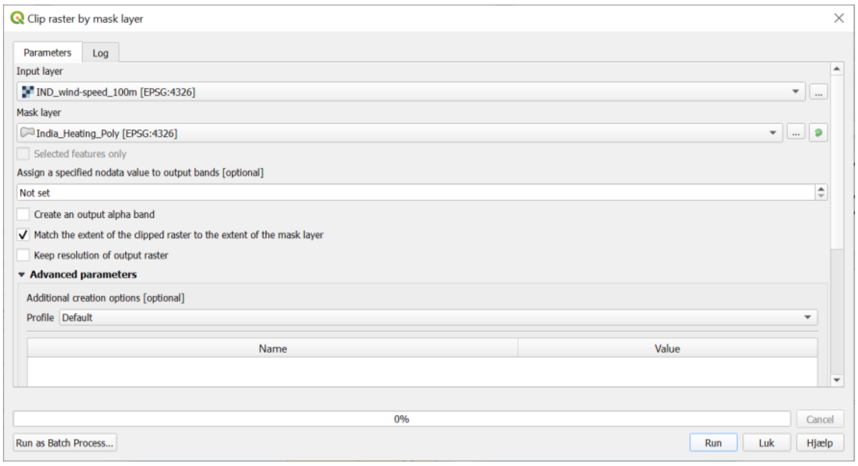


Figure 1.2: Clip by mask layer panel

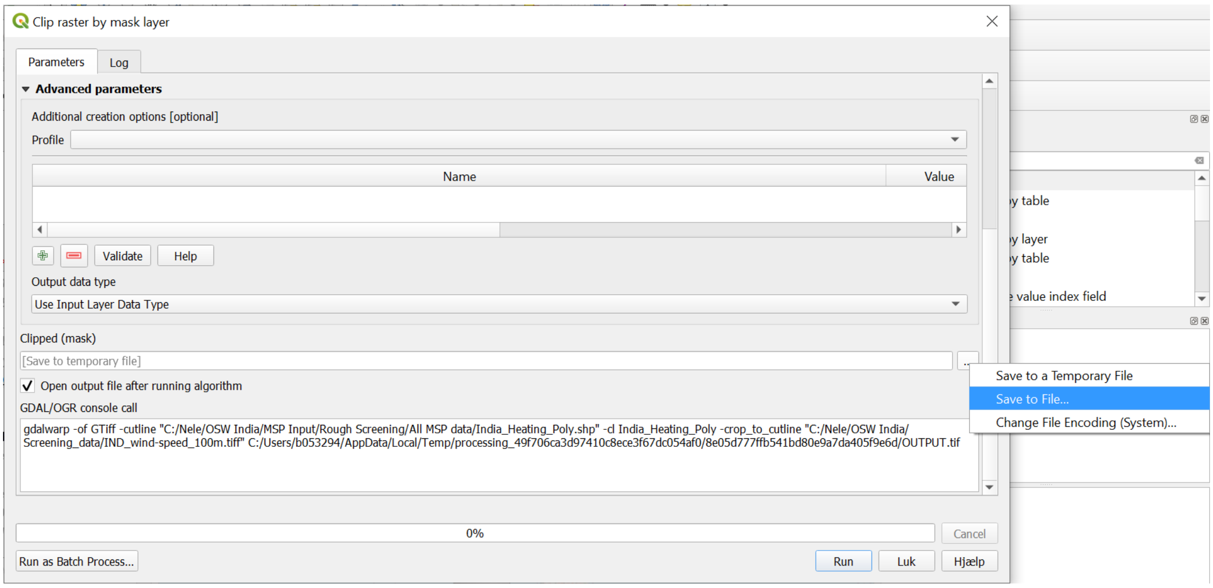


Figure 1.3: Clip by mask layer panel

Your output raster layer should look similar to the layer in figure 1.4.

2.2 Step 2. Reclassify the Bathymetry Data

We want to visualize the areas with the highest wind speeds and the lowest water depth. Therefore, we reclassify the bathymetry and wind speed data into relevant intervals in order to equalize the two components. To do so we need to open the **processing toolbox** in the user panel.

When the toolbox window opens, use the search feature and search → **reclassify**, see figure 1.5.

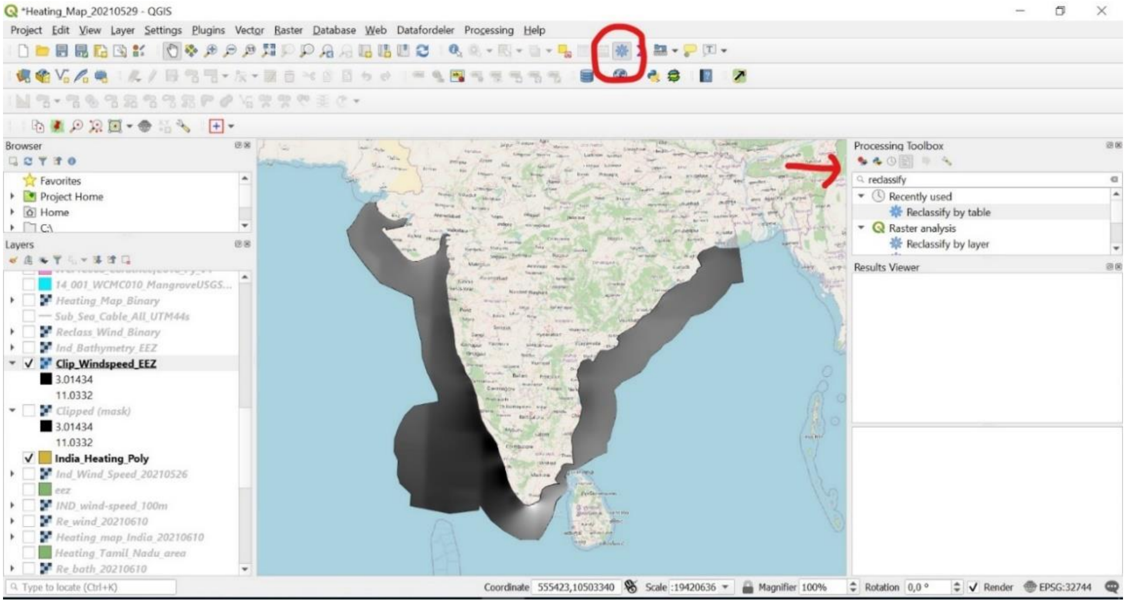


Figure 1.4: Clipped wind speed raster and processing toolbox

Click on **reclassify by table** and put in your 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 to your folder, see figure 1.5.

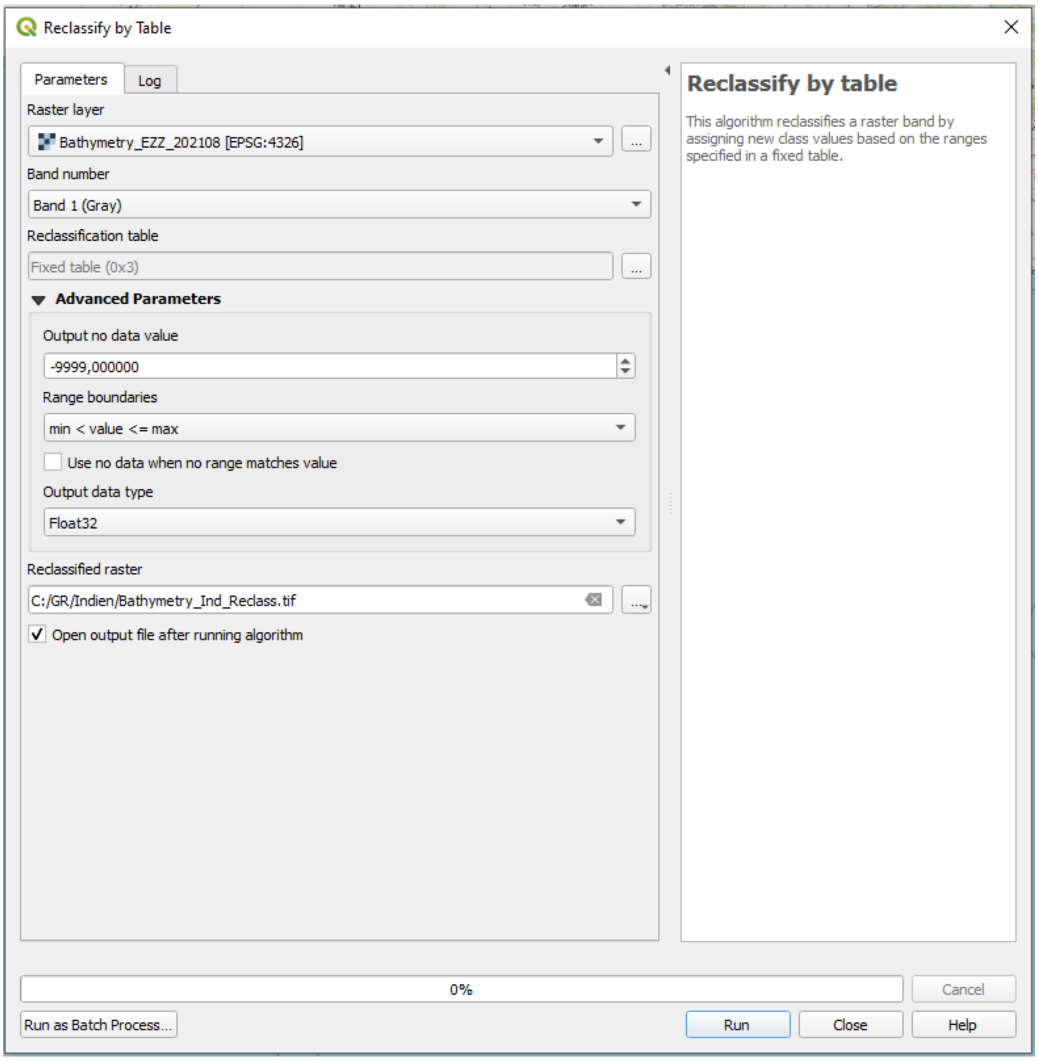


Figure 1.5 reclassify by table

Before clicking run, we need to set **the reclassification table.** Click  in order to open the **reclassification table**, a window should pop up, enabling you to add rows and insert your desired intervals, see figure 1.6.

In this example, we want to classify the bathymetry data into eight categories with the minimum relevant water depth = -50 m and the maximum water depth = 0 m.

For the bathymetry, we assign each water depth interval with a value from 1 to 8. With 1 being the least favorable water depth and 8 the best suitable water depth. The input values are exemplified in table 1.

Table 1: Input values for the reclassification table

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	0	8

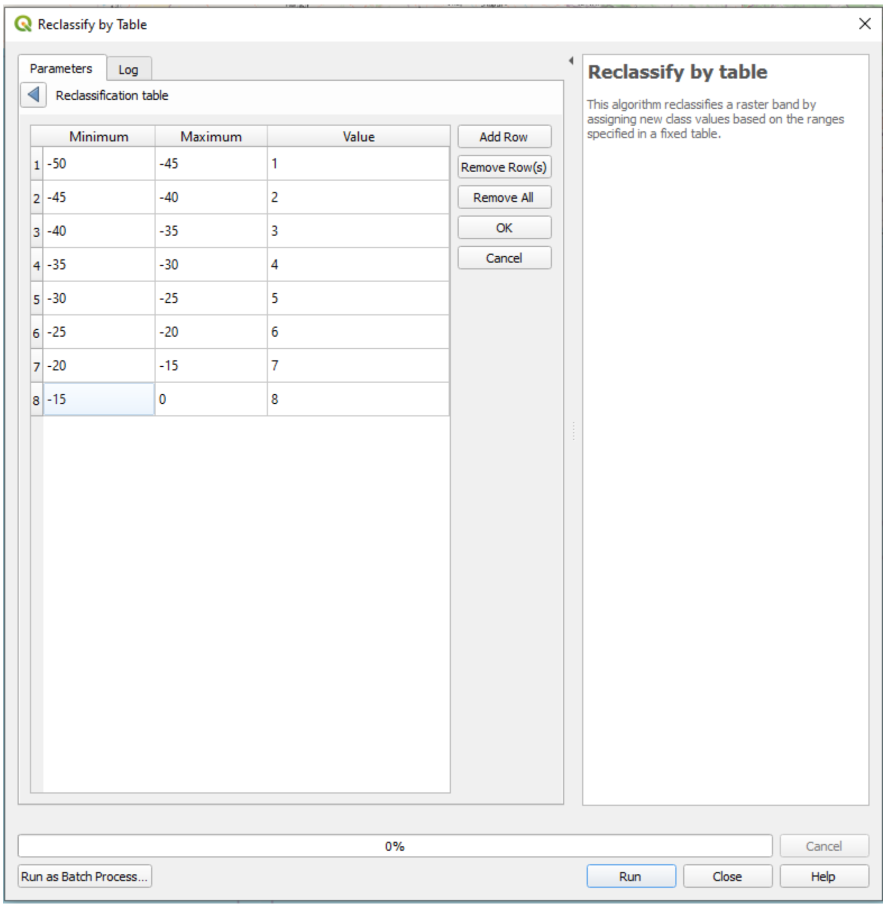


Figure 1.6 Example of the reclassify by table

After you added your chosen rows and your values, click **ok**. Make sure you saved the output file to your folder and click **run**. Your reclassified raster should look similar to the reclassified raster in Figure 1.7.

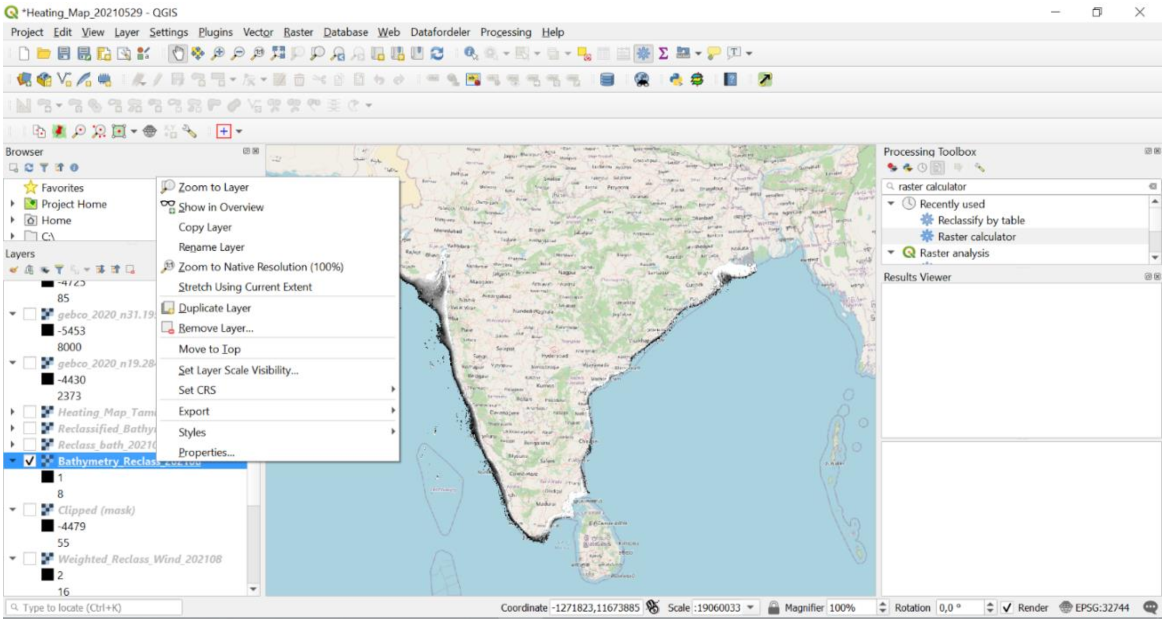


Figure 1.7: Example of reclassified bathymetry raster layer

2.3 Step 3. Reclassify the Wind Speed Data

We now want to reclassify the wind speed raster layer into relevant intervals. To do so, repeat the steps 1 and 2.

In this example, we divide the wind speed data 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, which is why we are weighing the wind speed values double. Instead of assigning values of 1-8 we are assigning values of 2-16. With 2 being the least favorable and 16 the best suitable wind speed. The input data is exemplified in table 1.2.

Table 1.2. Input data for the reclassification table

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

Your output bathymetry layer should look similar to Figure 1.8.

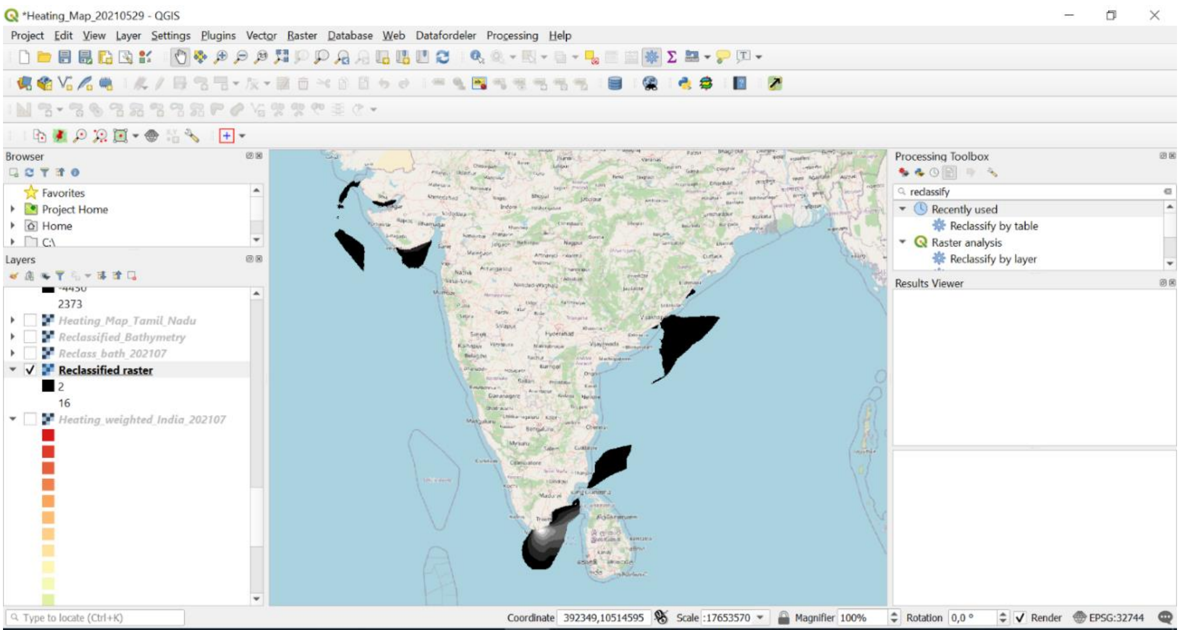


Figure 1.8: Example of reclassified wind speed layer.

2.4 Step 4. Raster Calculator

The next step is to use the **raster calculator** in order to combine the reclassified values. Since we are combining two raster layers on top of each other, we need no make sure they fit perfectly together. Therefore, one raster layer will serve as the reference layer. Before we start, we need to identify the pixel size of one of the two raster layers (bathymetry or wind speed).

In this example, we chose the bathymetry layer as the reference layer. Right click on your clipped, reclassified bathymetry layer and open **layer properties**, see figure 1.9. In the layer properties click on **information** in the left panel (Figure 1.9). Here, we can see the pixel size of the bathymetry raster layer is 0.0042 and we will use this value in the **raster calculator**.

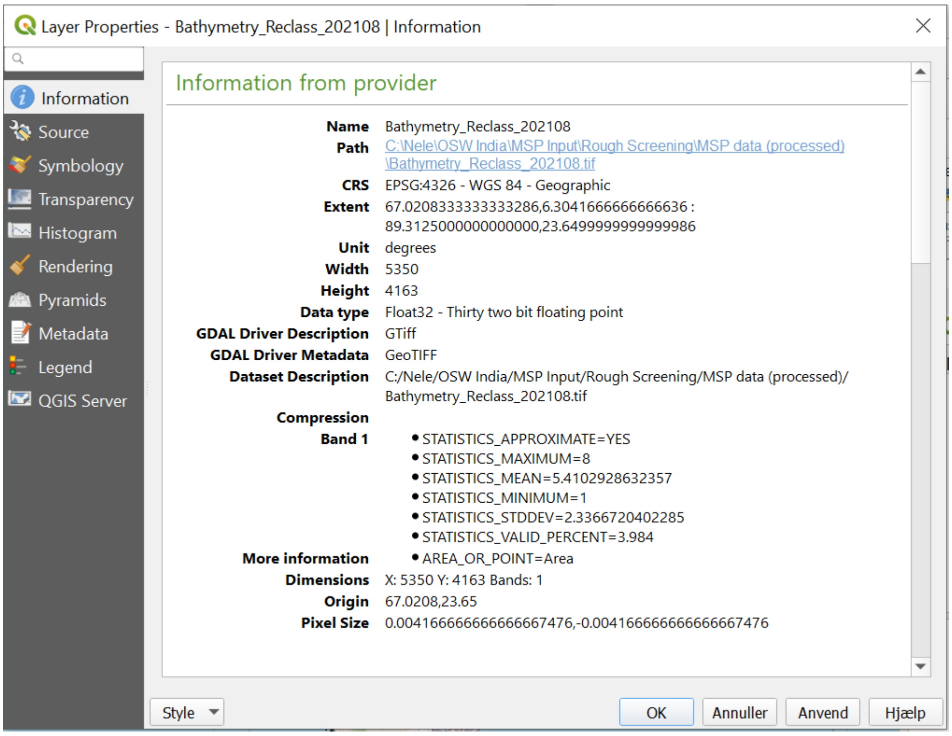


Figure 1.9: Layer properties

Search for **raster calculator** in the processing toolbox and click to open it. In the **raster calculator** panel, we now need to add the relevant layers in the expression panel. To do so, choose your weighted reclassified wind speed layer by double clicking it. The layer should be visible in the **expression** panel. Before adding the bathymetry layer, choose the **operator** you will use. In this case "+". Then, choose the reclassified bathymetry layer. The expression should be similar to the expression exemplified in Figure 1.10.

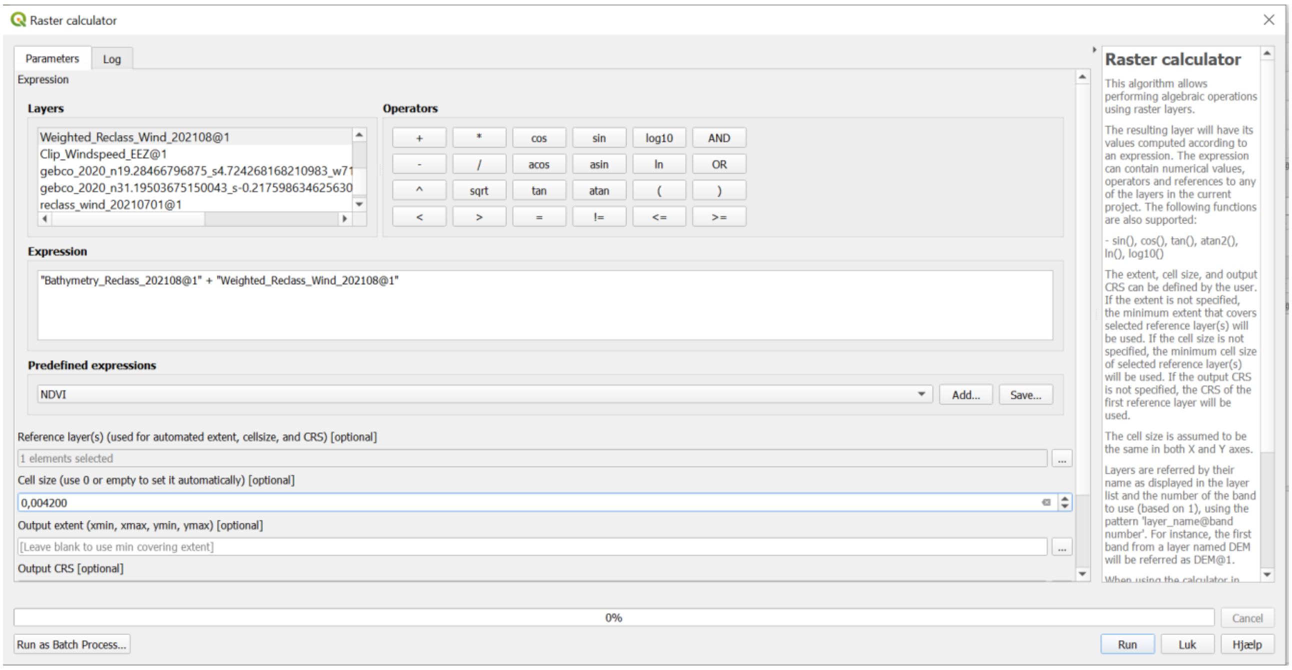


Figure 1.10: Raster calculator panel

Set the **cell size** to 0.0042 and make sure to save the output layer in to your folder. Before clicking on run, set the **reference layer(s)** to your classified bathymetry layer. See example in Figure 1.11. Click **ok,** then click **run**. The output is the final weighted heating map.

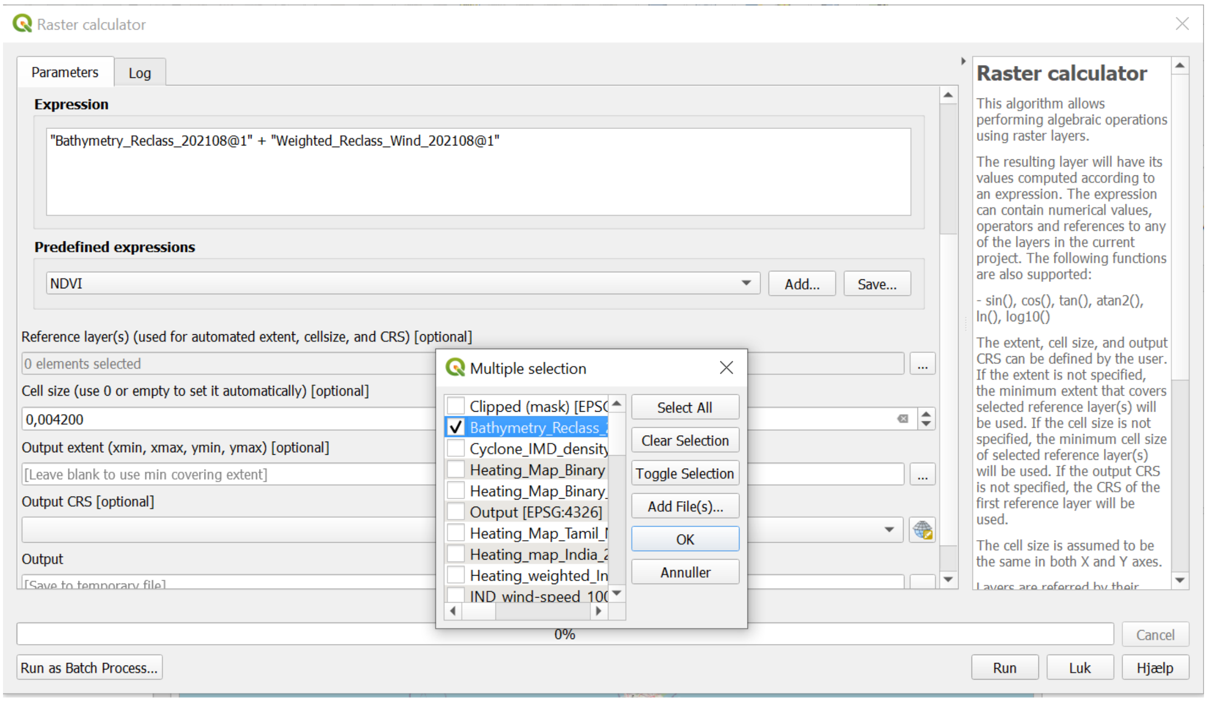


Figure 1.11: Raster calculator panel

2.5 Step 5. Classify the Result

We now have created a heating map that visualizes the most suitable sites for offshore wind locations in India. The last step is now to visualize the data correctly. To do so, open the **properties layer** by right clicking on the weighted heating layer you just created. In the left panel click on **symbology.** Set the **render type** to singleband pseudocolor. Set the mode to equal interval and set **classes** to 21. Chose a **color ramp** and click **ok**, see figure 1.12.

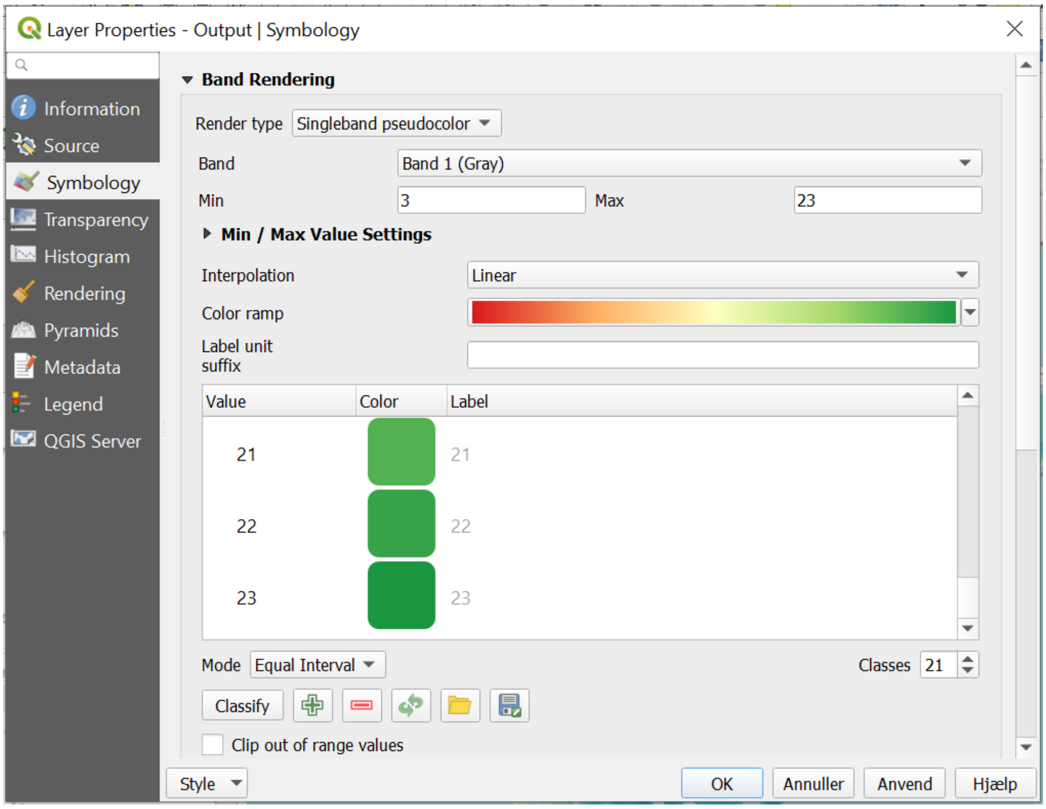


Figure 1.12: Layer properties: Symbology

Your resulting heating map should look similar to the heating map exemplified in Figure 1.13. We chose a color ramp from red to green. Thus, green symbolizes the best suitable sites, while red shows the least favorable sites.

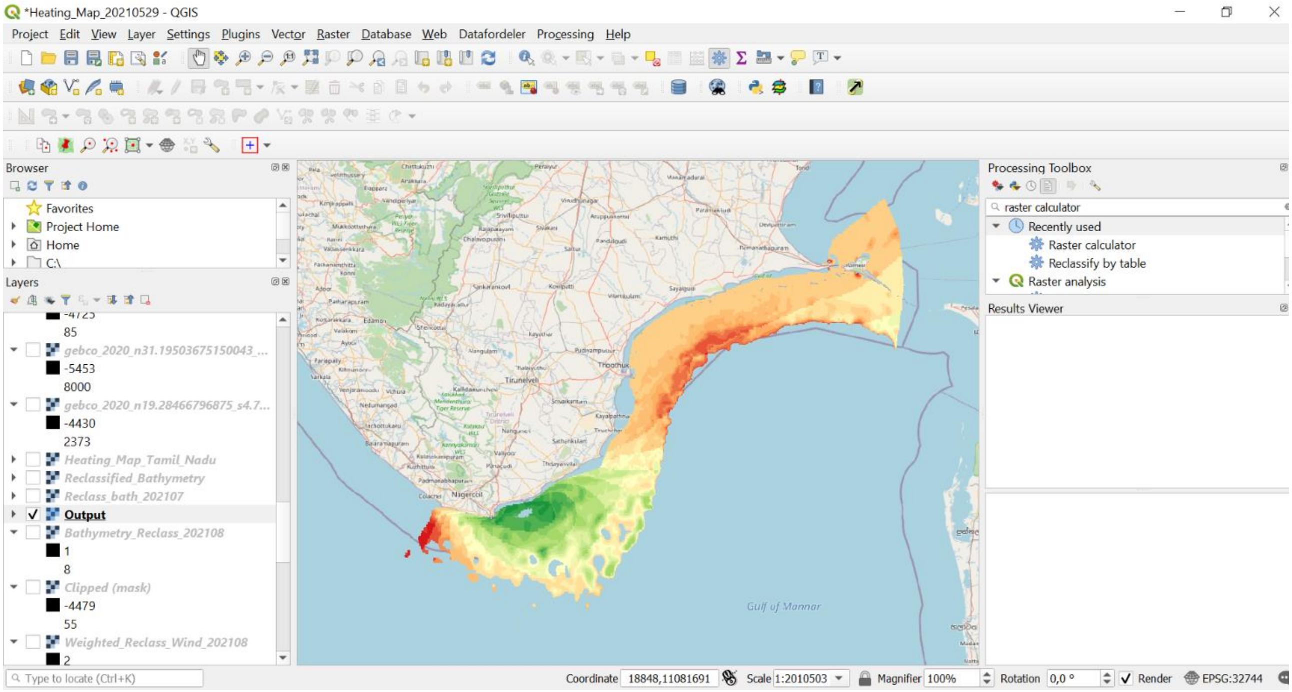


Figure 1.13: Finished heating map, zoomed in to south India.

3. Focus area 2 - LCOE Heat Mapping of India using QGIS

In this exercise, we use GIS and Excel to calculate the Levelized Cost of Energy (LCoE). We use GIS to find the geo-specific bathymetry and wind data (Weibull A and K) and thereafter calculate the LCoE using Excel. During this exercise we work with vector data which allows us to calculate the LCoE for a vast area, namely all of India. It also allows us to easily export the geo-specific data to an Excel worksheet and to store all the relevant data in one layer.

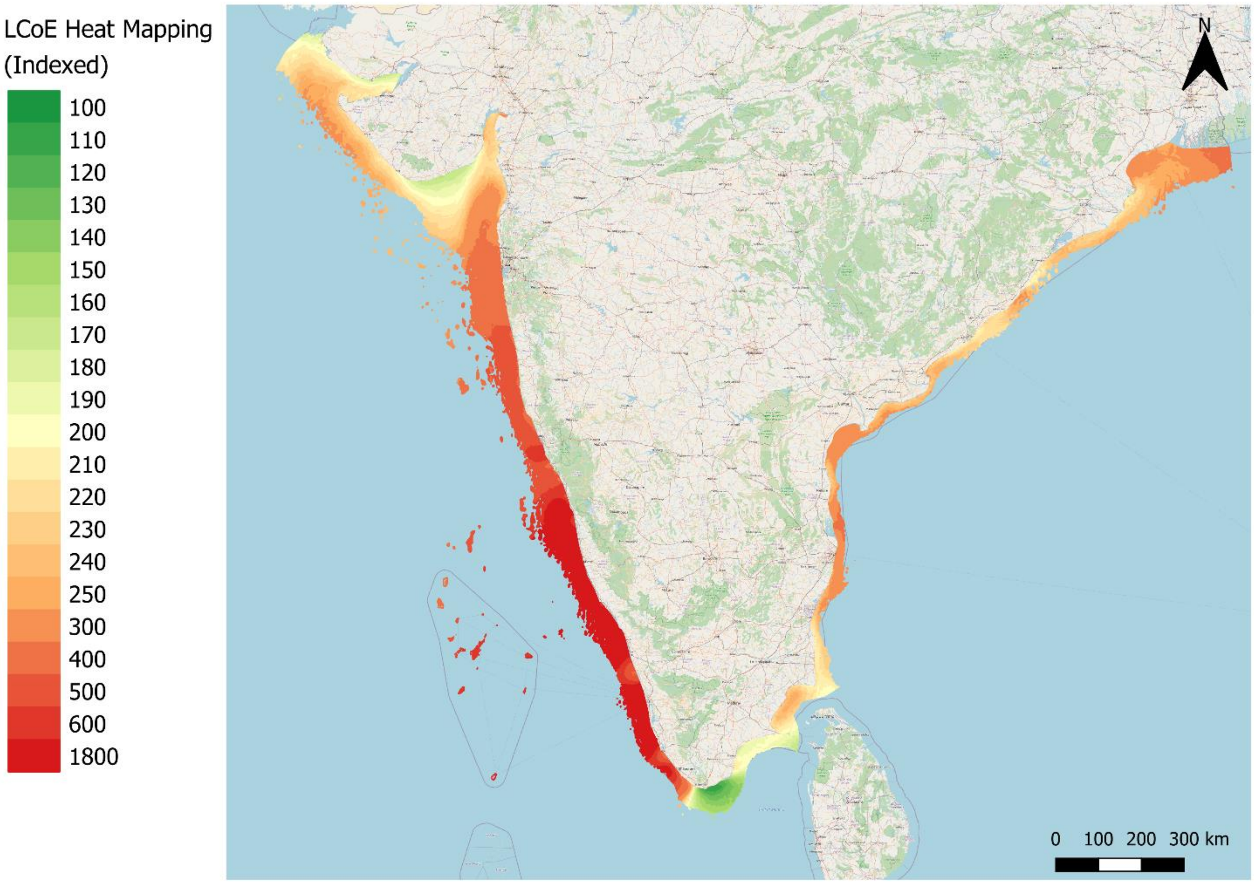


Table 2.: Data overview

Year of final investment decision		2025
Capacity per turbine	MW	15

Technical lifetime	years	27
Discount rate (WACC)	%	8,5
Electrical loss factor	%	9
Wake loss factor	%	7
Nominal investment for developer		
- Of which management		
o Development including surveys**	M USD/MW	0,068
o Project execution	M USD/MW	0,029
- Of which equipment		
Foundation coast based on water depth (m) [2]		
0 to 5	M USD/MW	0,16
5 to 15	M USD/MW	0,23
15 to 25	M USD/MW	0,29
25 to 35	M USD/MW	0,34
35 to 45	M USD/MW	0,38
45 to 55	M USD/MW	0,43
55 to 65	M USD/MW	0,47
o Wind turbine	M USD/MW	1,185
- Of which grid connection		
o Infield cables	M USD/MW	0,059
o Export cables onshore & offshore	M USD/MW	0,313
o Onshore windfarm substation	M USD/MW	0,088
o Offshore windfarm substation	M USD/MW	0,196
- Of which installation	M USD/MW	0,529
Total (real-20)	M USD/MW	2,80
Fixed O&M	USD/MW/year	63700

3.1 Step 1: Calculating the Energy Production

3.1.1 Process Weibull parameters (in QGIS)

Start by importing Weibull A (λ) and k to QGIS from **globalwindatlas.info.** You may use the following links:

1) https://globalwindatlas.info/api/gis/country/IND/combined-Weibull-A/150

2) https://globalwindatlas.info/api/gis/country/IND/combined-Weibull-k/150

We now want to vectorize the two raster layers. To convert your raster data:

Click raster in the menu bar → conversion → polygonise (from raster to vector), see figure 2.

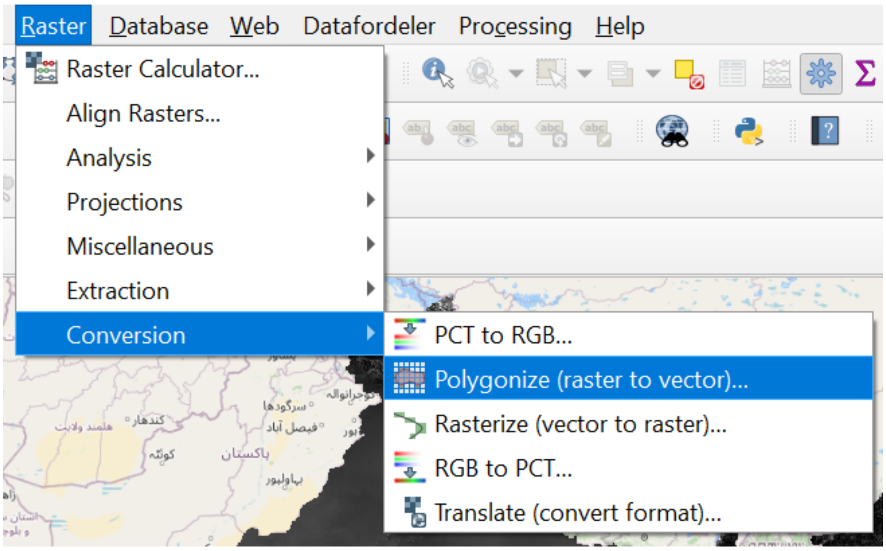


Figure 2: Polygonize (raster to vector)

Choose your **input layer** (e.g. the Weibull A layer) and save to file by clicking on the ... symbol.

Vectorising the data is necessary in order to store more than one type of information in an attribute table. Additionally, this results in lesser features and reduces the data volume.

Next, use the **Union tool** to merge both Weibull layers (A and k).

In the **processing toolbox → Union.** Select one Weibull layer as your input and the other Weibull layer as your overlay layer. It does not matter which layer is the in- or output. **Save to file** and click run, see figure 2.1.

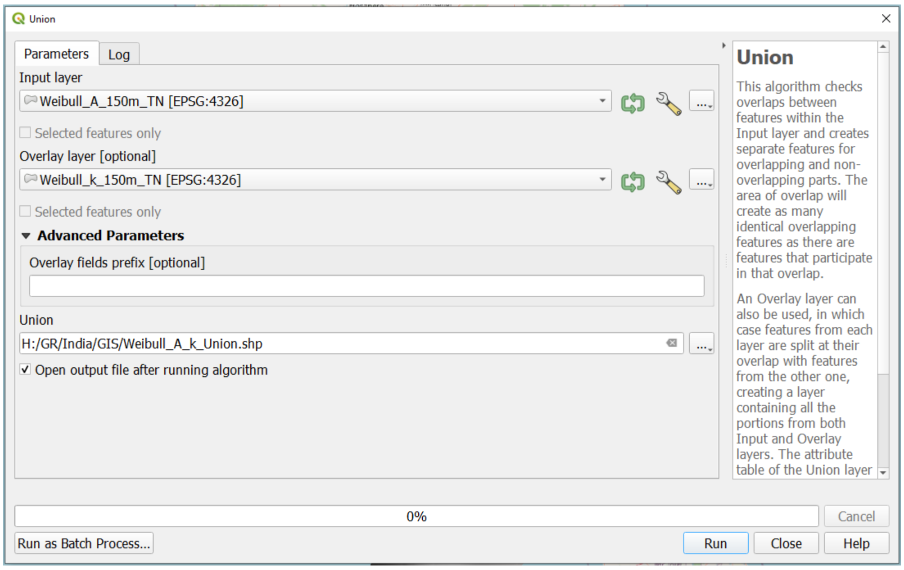


Figure 2.1: Union tool

Next, add an ID number to the unified Weibull layer by opening the attribute table and clicking on **field calculator** . Enable the box **Create a new field** and choose a field name. Set the output field type to **Whole number (integer)**. Lastly select **row_number** in the middle box so it shows up in the expression box. See figure X. An ID number can be helpful, especially when working with big datasets.

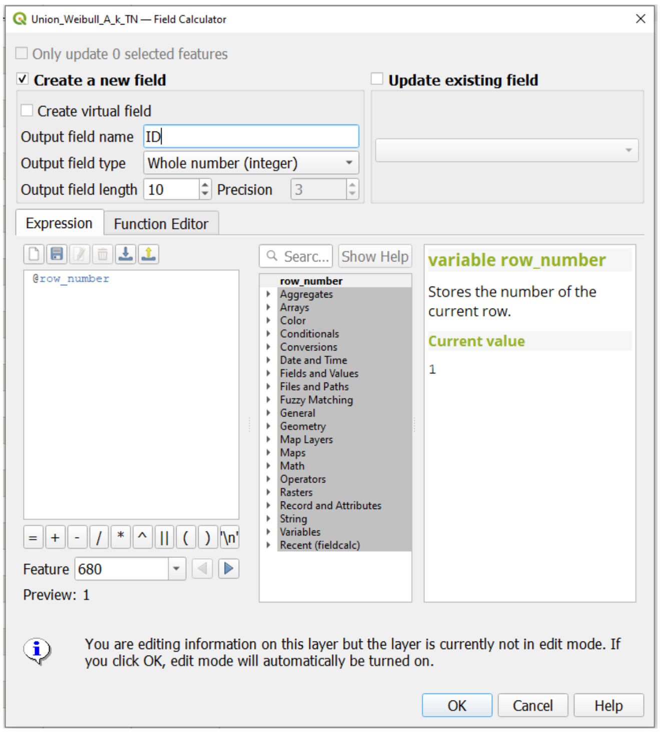


Figure 2.3: Field calculator – add row number

3.1.2 Find the foundation Cost

Table 2 on page 15 shows the foundation cost values for each water depth interval. Using QGIS we want to classify each feature by water depth and assign the right foundation cost.

In QGIS, find the mean water depth for each area using **Zonal Statistics** in *the **processing toolbox*** – click **Statistics to Calculate** and choose ***mean***, *see figure 2.4.*

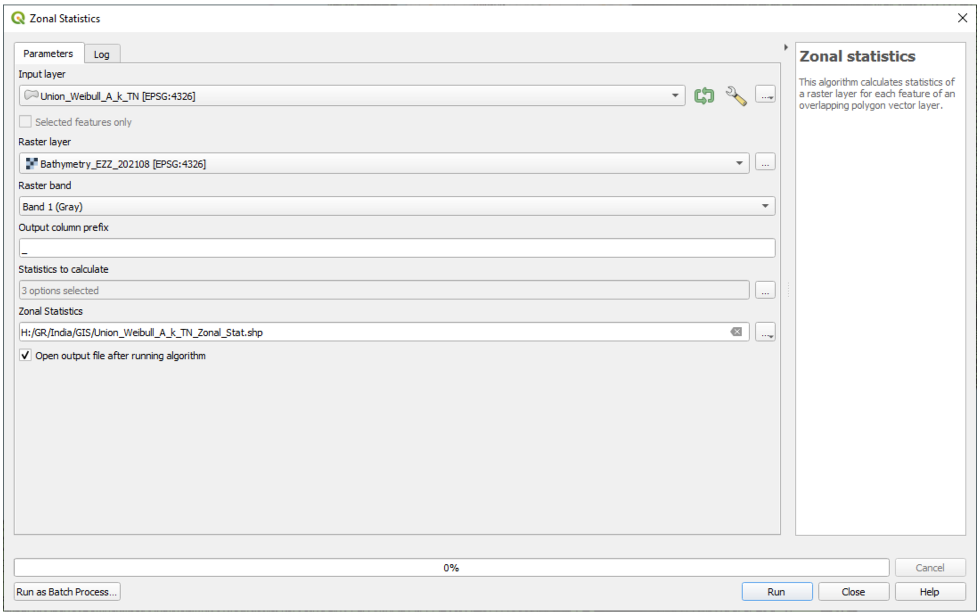


Figure 2.4: Zonal Statistics

Next, assign each water depth the correct foundation cost. To do so **add a new field** in the attribute table. Next, use the **select by expression** feature in the attribute table to select all features with a water depth from 0-5 meters. Use the newly added field in the attribute table to assign the correct foundation cost (see figure 2.5).

Continue these steps with all intervals (0-5, 5-15, 15-25, 25-35, 35-45, 45-55, and 55-65).

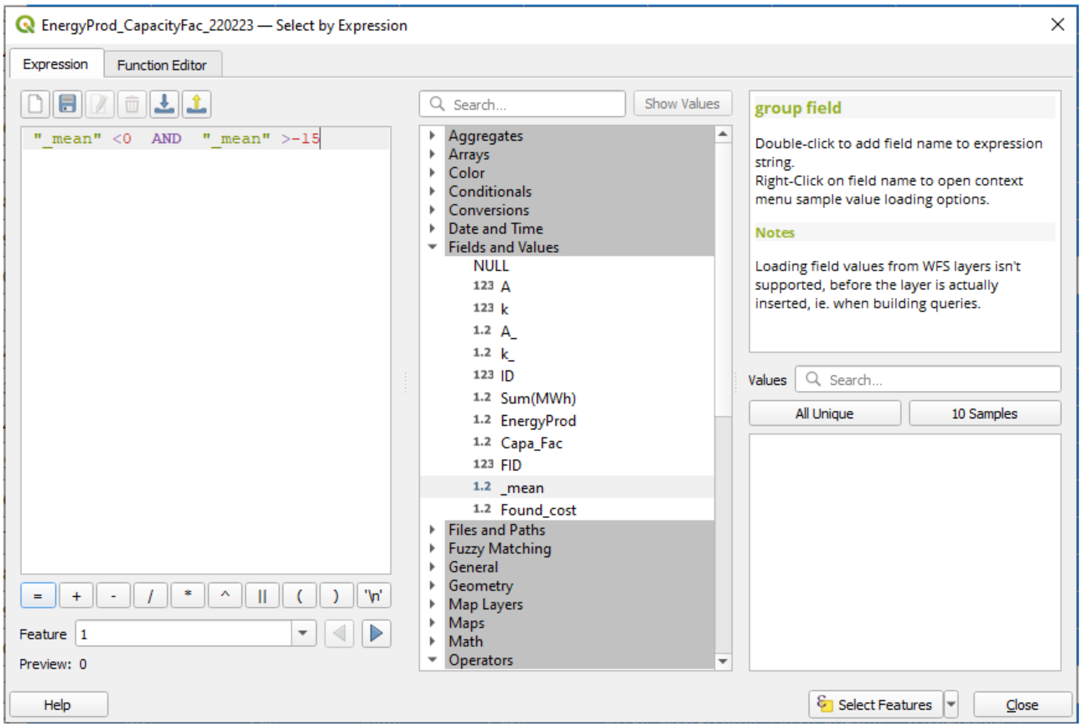


Figure 2.5: Select by expression

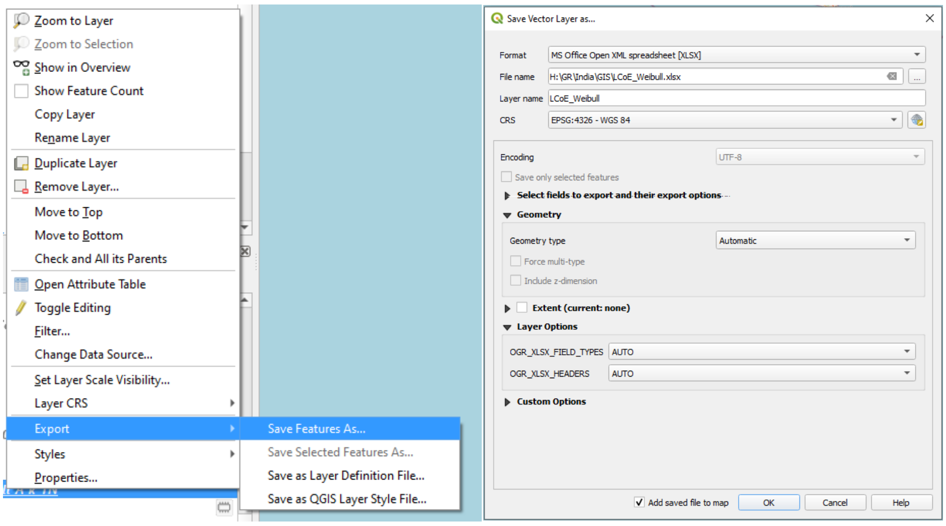
Next, we export the layer to Excel. With that done, we lastly need to add all other costs to the specified foundation cost (table 2) to get the **total investment cost**. The total investment cost is needed to calculate the CAPEX in step 3.

Now we can export the layer table to Excel.

Layer → Export → Save features as…

In the drop-down menu choose: *MS Office Open XML Spreadsheet*.

Save to file and click **ok**



3.1.3 Make a frequency distribution table (in Excel)

We now need to make a frequency distribution table using the Weibull A (λ) and k values for all features and multiply by 8766 hours. Open .xlsx file you created with the unified Weibull values and ID number. Use the WEIBULL.DIST function in Excel to calculate a frequency distribution table. This is an array (length = 30) for each feature.

Next, import the power curve (length=0-30 m/s) and multiply the frequency distribution table with the power curve. Sum the result for each feature and multiply the result with the indexed WACC and loss factor to get the **energy production per feature** (MWh), see table 2.1.

The resulting values of the energy production (MWh) for India should ca. range between 21596-77642 MWh, when using the methods described in this guide (see also table 2.2).

Table 2.1: Intermediate results

WACC	%	8,5	**(1-0,085)**	0,915
Loss Factor	%	16	**(1-0,16)**	0,84
Capacity	MW	15	**15*8766**	131490
Technical Lifetime	years	27		
OPEX		63700		

3.2 Step 2: Calculating the Capacity Factor

Calculate the **capacity factor** by dividing the energy production with the capacity. The capacity factor should range between 16-59 %, when using the methods described in this guide (table 2.2).

Table 2.2: Results of the LCoE calculation in this GIS-guide

Energy Production	**MWh**	**21596 - 77647,4**
Capacity Factor [1]	**%**	**16,4 - 59**
LCoE	**USD/MW**	**82,3 - 308**

3.3 Step 3: Calculating Capex

In order to calculate Capex, we needed to find the foundation cost based on the water depth. We did that in step 1.2, page 18. Now, we can calculate CAPEX in Excel using the PMT function.

CAPEX =PMT(*discount*; *technical lifetime*; *total investment cost*)

3.4 Step 4: OPEX

The OPEX cost used in calculating the LCoE is a fixed cost with a unit of USD per MW per year. It has been obtained as a result of stakeholder management with several internationally recognized sources. The detail explanation of the cost breakdown and explanation can be found in the FIMOI report, which is created as part of the India – Denmark energy partnership program.

3.5 Step 5: Calculating LCoE

The Levelized cost of Energy can be calculated usind thew following formula:

$$\text{LCoE} = \frac{CAPEX+OPEX}{Energy\ Production}$$

The LCoE values should range between 82 – 308 USD/MW when using the methods described in this guide (see figure 2.6).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	A_	k_	_mean	ID	Sum(MWh	EnergyPro	Capa_Fac	Found_cost	Invest_tota	CAPEX	OPEX_fix	Capex_dis	Opex_dis	LCoE	CAPEX LCOE	MWh/MW/ye	OPEX LCOE
2	8,78	2,79	-5,79674	1	59256,28	45544,38	34,63714	0,23	2,697	257726,0051	6087,18818	3865890	91307,82	86,88664	77,66687427	3318,35171	19,19627742
3	8,77	2,78	-4,94833	2	59106,45	45429,22	34,54956	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,89821	75,8428141	3309,9614	19,24493741
4	8,8	2,85	-4,29574	3	59654,71	45850,61	34,87003	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,11796	75,14578635	3340,66352	19,06806824
5	8,78	2,8	-4,50588	4	59280,35	45562,87	34,65121	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,64917	75,62033792	3319,69936	19,1884846
6	8,78	2,79	-4	5	59256,28	45544,38	34,63714	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,68355	75,65104883	3318,35171	19,19627742
7	8,76	2,78	-3	6	58980,63	45332,51	34,47602	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	85,07932	76,00460745	3302,91539	19,28599209
8	8,76	2,78	-2,28289	7	58980,63	45332,51	34,47602	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	85,07932	76,00460745	3302,91539	19,28599209
9	8,76	2,92	-4	8	59302,43	45579,85	34,66412	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,61766	75,59218087	3320,9359	19,18133981
10	8,77	2,92	-4	9	59432,59	45679,89	34,7402	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,43233	75,42662378	3328,22516	19,13933008
11	8,79	2,86	-4	10	59551	45770,9	34,80941	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,26445	75,27664979	3334,856	19,10127453
12	8,79	2,86	-2,51568	11	59551	45770,9	34,80941	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,26445	75,27664979	3334,856	19,10127453
13	8,79	2,85	-3	12	59527,13	45752,55	34,79546	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,29824	75,30683625	3333,51924	19,10893428
14	8,79	2,84	-3,93657	13	59503,17	45734,14	34,78146	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,33218	75,33715328	3332,17777	19,11662715
15	8,79	2,91	-3,02458	14	59669,11	45861,68	34,87845	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,09766	75,12764992	3341,46999	19,06346616
16	8,79	2,9	-3	15	59645,65	45843,65	34,86474	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,13073	75,15719471	3340,15643	19,07096308
17	8,79	2,87	-2,65375	16	59574,79	45789,18	34,82332	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,23081	75,24659315	3336,18808	19,09364773
18	8,79	2,84	-2,96241	17	59503,17	45734,14	34,78146	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,33218	75,33715328	3332,17777	19,11662715
19	8,78	2,83	-3,29574	18	59352,03	45617,97	34,69311	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,54693	75,529001	3323,71386	19,16530807
20	8,77	2,8	-3,32042	19	59154,04	45465,79	34,57738	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,82992	75,78180573	3312,6261	19,22945667
21	8,77	2,79	-3,82042	20	59130,29	45447,54	34,56349	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,86399	75,81224359	3311,29611	19,23718021
22	8,77	2,78	-3,70426	21	59106,45	45429,22	34,54956	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,89821	75,8428141	3309,9614	19,24493741
23	8,77	2,81	-3,68546	22	59177,7	45483,98	34,59121	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	84,796	75,75149975	3313,95138	19,2217666
24	8,76	2,79	-3	23	59004,15	45350,59	34,48976	0,16	2,627	251036,7873	6087,18818	3765552	91307,82	85,04541	75,97431392	3304,23237	19,27830518

Figure 2.6: Data of the LCoE calculation in this GIS-guide in Excel

4. Focus Area 3 - Rough Screening for Suitable Offshore Wind Sites

A rough screening is the initial screening phase, and is performed to determine which offshore areas are both suitable/feasible and available for wind farming.

A fast and easy way to get an idea of the already in use maritime space one can make a map – a rough screening – of the future offshore wind area. See figure 3.

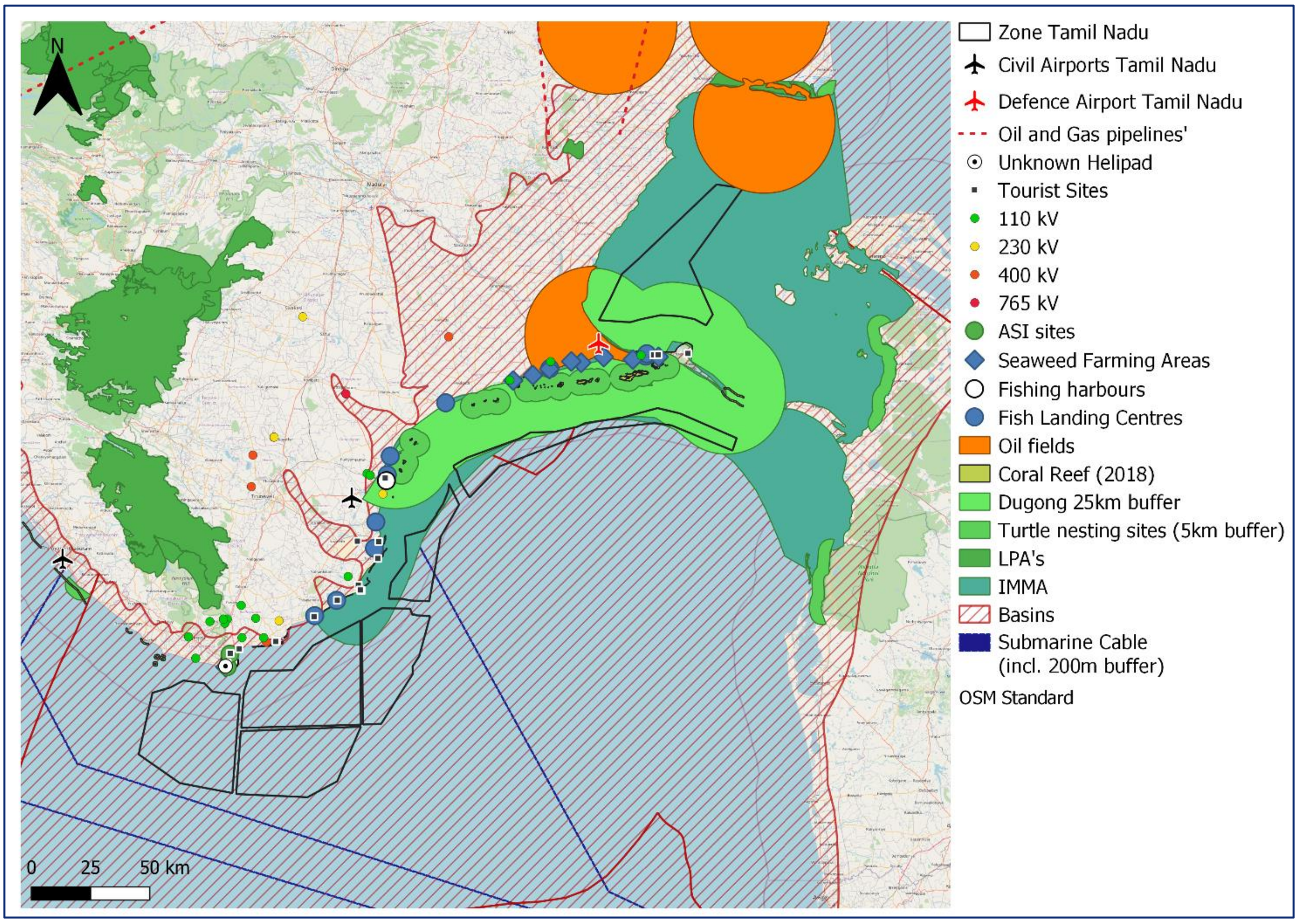


Figure 3: Restriction (negotiation) zones and no-go areas

4.1 Offshore wind potential – the Danish model

In Denmark, the rough screening is carried out using a spatial analysis method called overlay analysis. This theoretical assessment is based around geodata of existing reservations of the maritime space. The result is a GIS layer that shows the quantified offshore wind potential by simply extracting the already existing area interests. Dividing the space into available, restricted/negotiable and no-go areas. See table 3 below.

The rough screening process is carried out by using an **overlay analysis in QGIS**. The aim of an overlay analysis is to compute a dataset that combines all relevant spatial information. Generally, data on bathymetry, wind speed and availability are combined into one dataset in order to identify the desirable locations that meet all requirements.

In order to allocate sites for offshore wind we first need to know what areas we can't use. Therefore, we organize all our data according to the different data-groups:

- No-go areas
- Areas to negotiate
- Physical limitations

Table 3 shows a color-classification scheme based on the data-groups that need to be identified before starting the screening.

- Subgroup A (green) is the usable space we want to determine
- Subgroup B (yellow) is the negotiable space
- Subgroup C is the free or negotiable space that lies outside the feasible physical boundaries (e.g. low wind conditions)
- Subgroup D is the space that is not available

Note that the information in Table 3 serves as an example only. Values may be changed to fit different projects. To begin the rough screening process, all input factors should be determined and thorough data processing is important. Input factors typically include physical limitations (bathymetry- and wind speed data), selected "no-go" areas (shipping lanes, protected environmental sensitive areas etc.) and negotiable areas. The input factors are combined by using the **merge vector** tool and the **union tool** in QGIS. With a **select by attributes** inquiry, the considerable sides are selected and classified into four sub-sections. The subsections indicate whether the area is free to use or in conflict with other plans and whether the area is within the physical limitations or not.

Table 3: Data for determine feasible sites for offshore wind farming. Based on the four subgroups a, b, c and d in table 2 it can later be determined where the feasible areas are located.

Subgroup	*No-go*	*Restriction zone/areas to negotiate*	*Water depth*	*Distance*	*Wind speed*	*Description*
A	*No*	*No*	*<50m*	*>15km*	*>7m/s*	*No other area interests, depth < 50m*
B	*No*	*Yes*	*<50m*	*>15km*	*>7m/s*	*Known areas to negotiate, depth < 50m*
C	*No*	*Yes + No*	*>50m*	*>15km*	*<7m/s*	*Outside no-go areas, depth >50m*
D	*Yes*	*Yes + No*	*>50m*	*>15km*		*No-go areas*

4.2 Step 1. Convert Raster to Polygons

To begin with, all input data must be **polygon features**. Therefore, both bathymetry and wind speed data need to be **converted** into **polygon features**.

To convert your raster data, click **raster** in the menu bar → conversion → polygonise (from raster to vector).

Make sure to use the clipped raster we created in **Focus Area 1**, otherwise, the conversion process will be time-consuming.

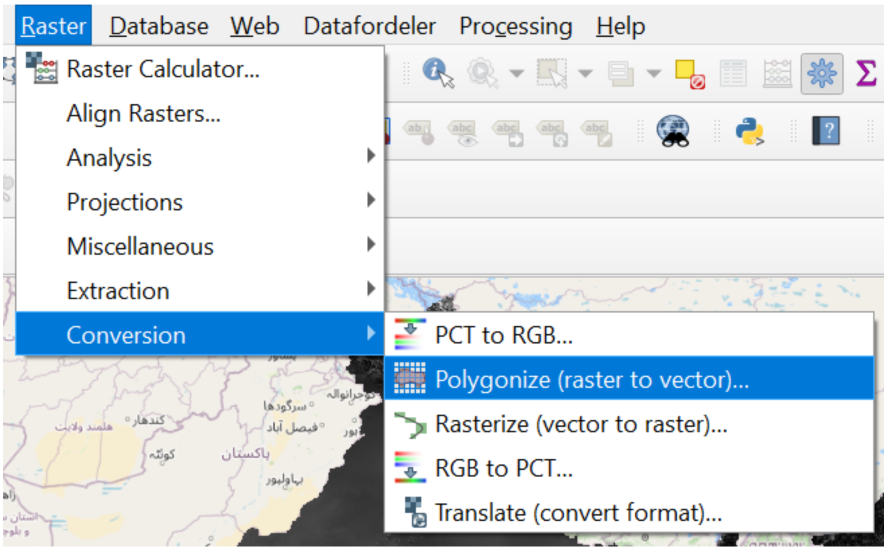


Figure 3: Polygonize (raster to vector)

Choose your **input layer** (e.g. the wind-speed layer) and save to file by clicking on the [...] symbol.

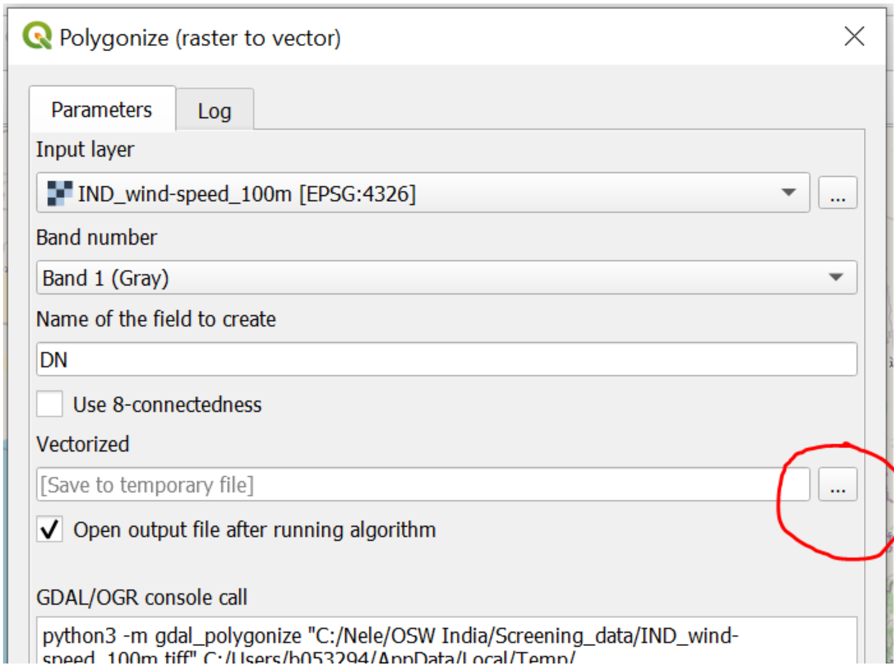


Figure 3.2: Polygonize (raster to vector)

4.3 Step 2. Combining Data into Data-groups

Next, we are going to create one layer for each data-group using the **merge** and **union tool** in QGIS:

- One layer combining all physical limitations (Section 3.1)
- One layer combining all no-go areas (Section 3.2)
- One layer combining all areas to negotiate (Section 3.3)

4.3.1 Creating one layer with all physical limitations

We want to create a layer that combines water depth, wind speed and distance to shore into one layer. However, we cannot simply merge the three layers since each layer contains different types of information that we want to keep. Therefore, we are using the **union tool** instead, overlapping layers will thus contain up to three set of information in the attribute table.

[Tip: How overlay works]

Start by adding the polygonised **bathymetry** and **wind speed** layer to your map.

Now, we need to create a layer that shows us the **distance** to the shore by creating buffers around the Indian coast. You may use the link below to download a boundary layer of India:

https://www.igismap.com/download-india-boundary-shapefile-free-states-boundary-assembly-constituencies-village-boundaries/

Use the **boundary layer** to create **buffers** around the shore in distances from 10km to 100km.

This is done by clicking on vector → geoprocessing tools → buffer

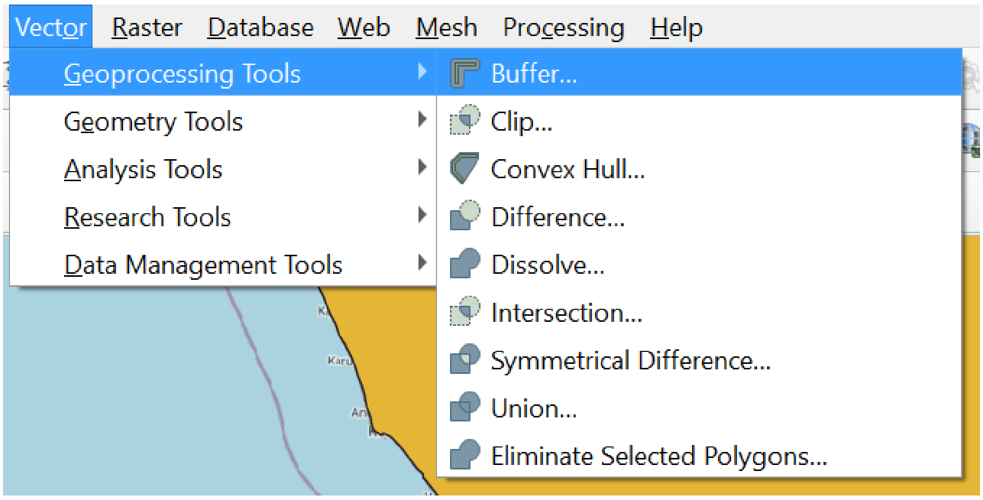


Figure 3.3: How to find the 'Buffer' geoprocessing tool

Select the **boundary layer** and set the distance to 10km. **Save to file** and click **run.**

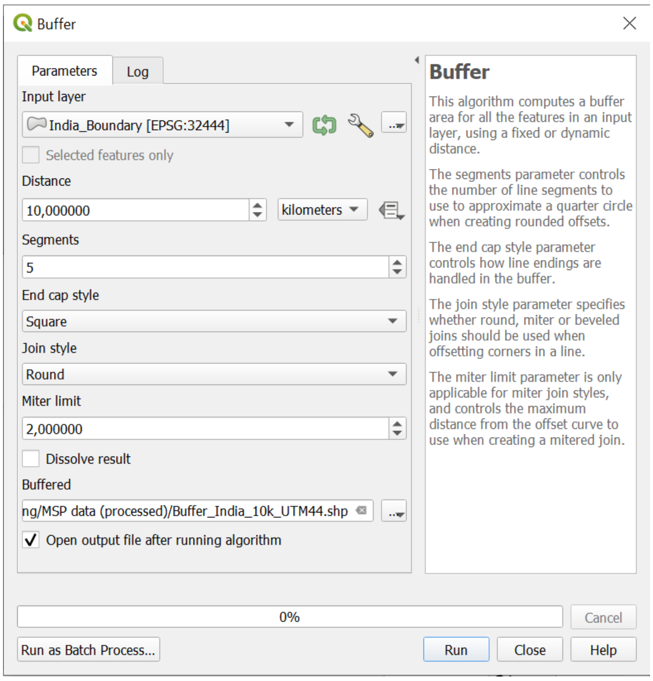


Figure 3.4: Insert parameters for the 'Buffer-tool' in QGIS

Repeat this step by increasing the distance with 10km each time until you have 10 buffer layers ranging from 10-100km around the Indian boundary.

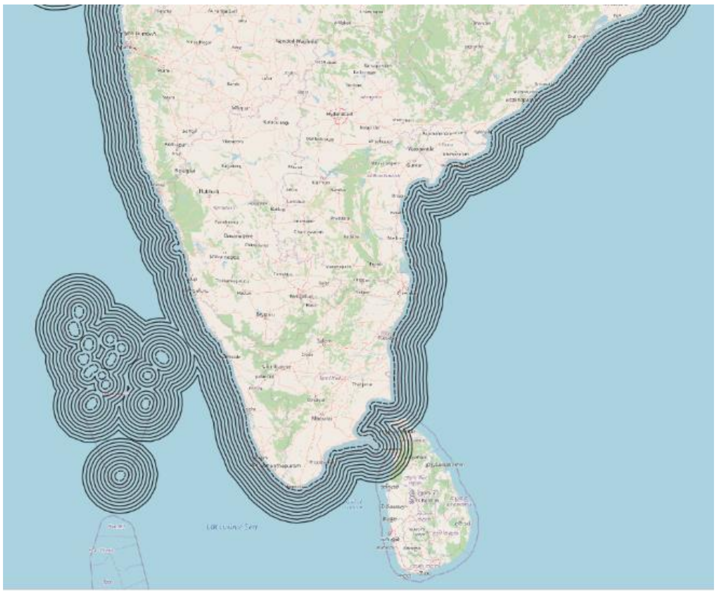


Figure 3.5: The 10 buffer layers (10-100km from the coast)

Next, click vector → geoprocessing tools → union

Use the **10km buffer** you created as **input** and the **20km buffer** you created as your **overlay layer**. **Save layer to file** and click **run**.

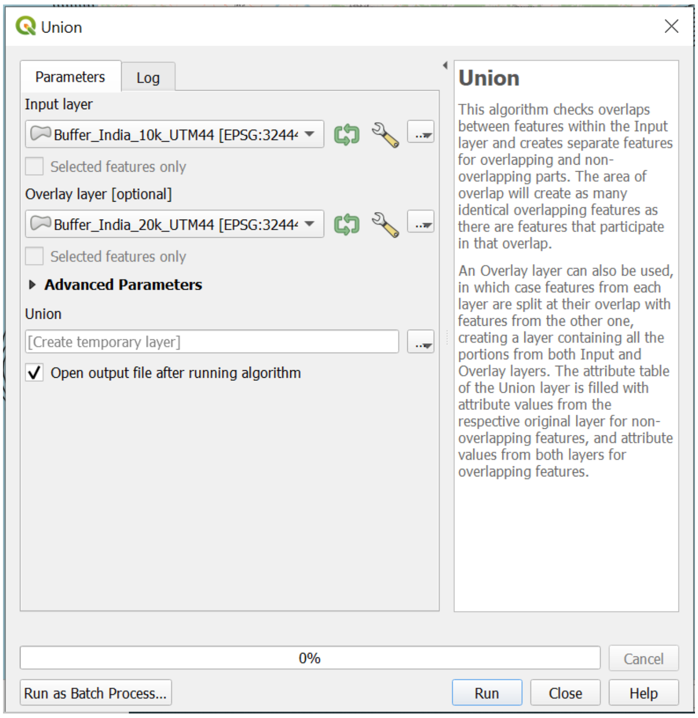


Figure 3.6: The 'Union-tool' in QGIS

We want to unify all of the 10 buffer layers we created into one layer; however, QGIS does not enable to unify multiple layers at once. Therefore, open the **union tool** again and use the layer you just created as **input** and the **30km buffer** as your **overlay layer**. Name this layer and save to file. Continue unifying the latest output with the next buffer layer (40km, 50km, 60km… 100km). Your distance layer should look like in the figure below.

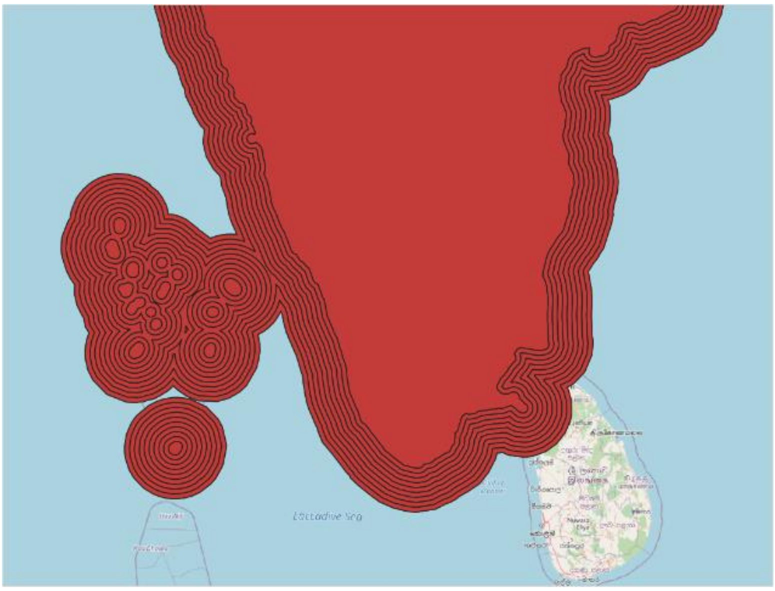
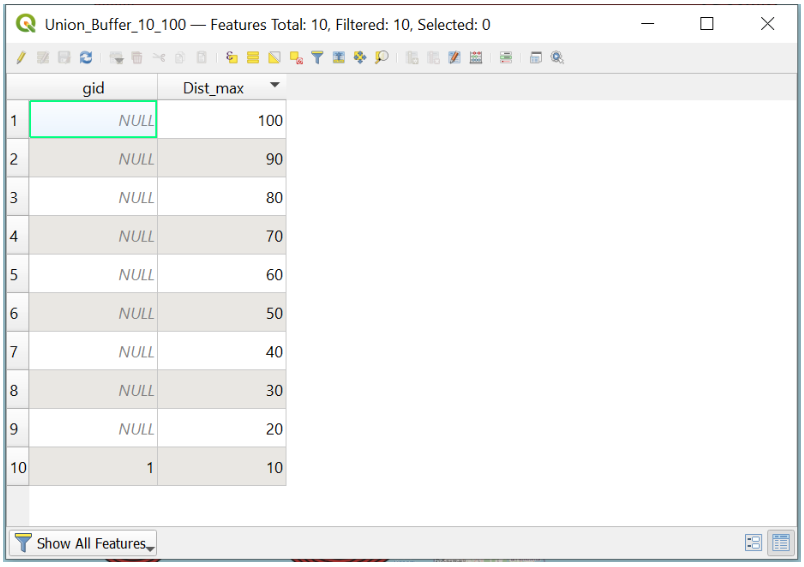


Figure 3.7: Example of the unified buffers (10-100km from the coast)

Open the attribute table of your distance layer and add a new field by enabling editing and clicking on add new table. In the new field, specify the distance. See figure below.



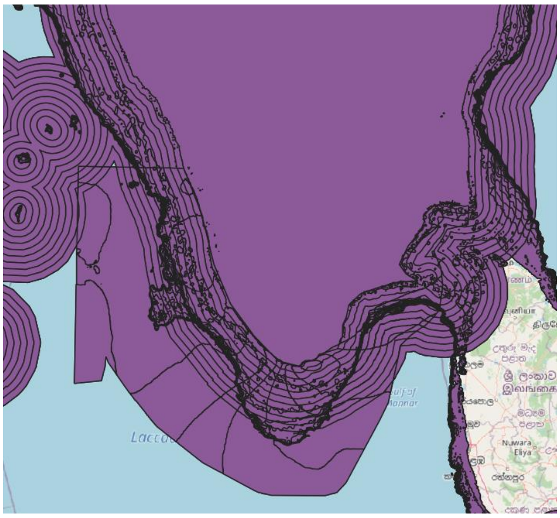
	gid	Dist_max
1	NULL	100
2	NULL	90
3	NULL	80
4	NULL	70
5	NULL	60
6	NULL	50
7	NULL	40
8	NULL	30
9	NULL	20
10	1	10

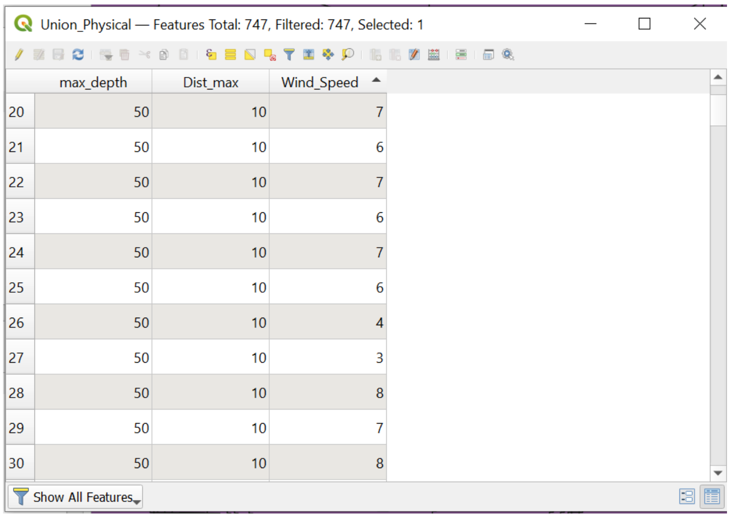
3.8: Attribute table of the unified buffer-layer in QGIS

Now that we have created a distance layer, we can combine it with the bathymetry and wind speed layer.

Open the **union tool** again and choose your *distance layer* as **input** and your polygonised bathymetry layer as **overlay layer**. Save to file and click **run**.

Lastly, open the **union tool** again and choose your unified bathymetry and distance layer as **input** and your polygonised wind speed layer as **overlay layer**. **Save to file**. You have now created a layer that contains all data of the relevant physical limitations.





Union_Physical — Features Total: 747, Filtered: 747, Selected: 1

	max_depth	Dist_max	Wind_Speed
20	50	10	7
21	50	10	6
22	50	10	7
23	50	10	6
24	50	10	7
25	50	10	6
26	50	10	4
27	50	10	3
28	50	10	8
29	50	10	7
30	50	10	8

Show All Features

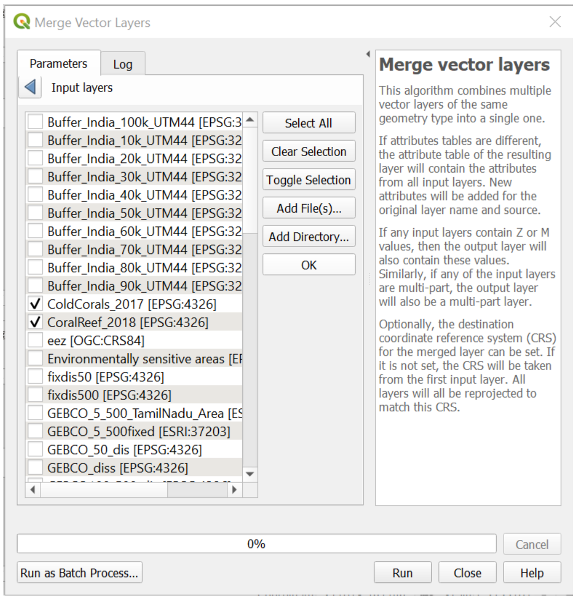
Figure 3.9: Example of the unified layer of the relevant physical limitations (left) and attribute table (right)

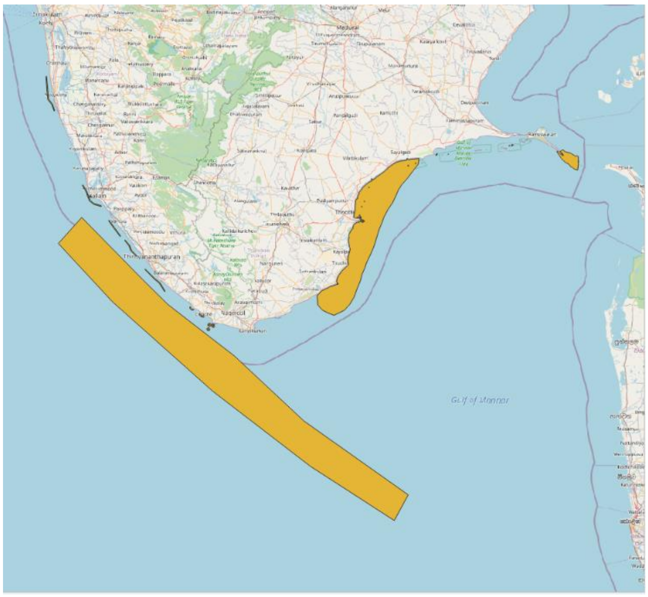
4.3.2 Creating one layer combining all no-go areas

To combine all data of no-go areas we simply want to **merge** all relevant layers and add a new field in the attribute table where we specify that these area are not available.

Click vector → data management tools → merge by vector.

Click the  button to choose the layers to merge. Make sure to select all the layers that classify as no-go areas. In this example, we are merging the international shipping lane and environmental sensitive areas (mangrove, seagrass and coral reefs). Click **OK** and then **save to file**. Click **run.**





3.10: Merge vector layers tool in QGIS (left) and example of merged 'no-go' areas (right)

Next, add a new field  and set the **type** to text (string) like in the figure below.

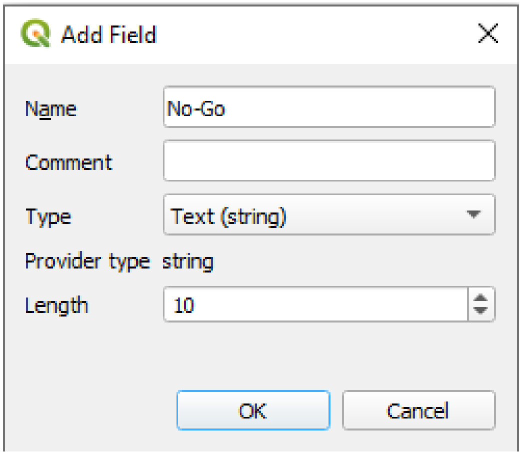


Figure 3.11: 'Add field' window in QGIS

Assign the value **'Yes'** to all features by using the expression panel. Select the field you just created and write the expression **'Yes'**. Afterwards, click **Update all**, see also the figure below.

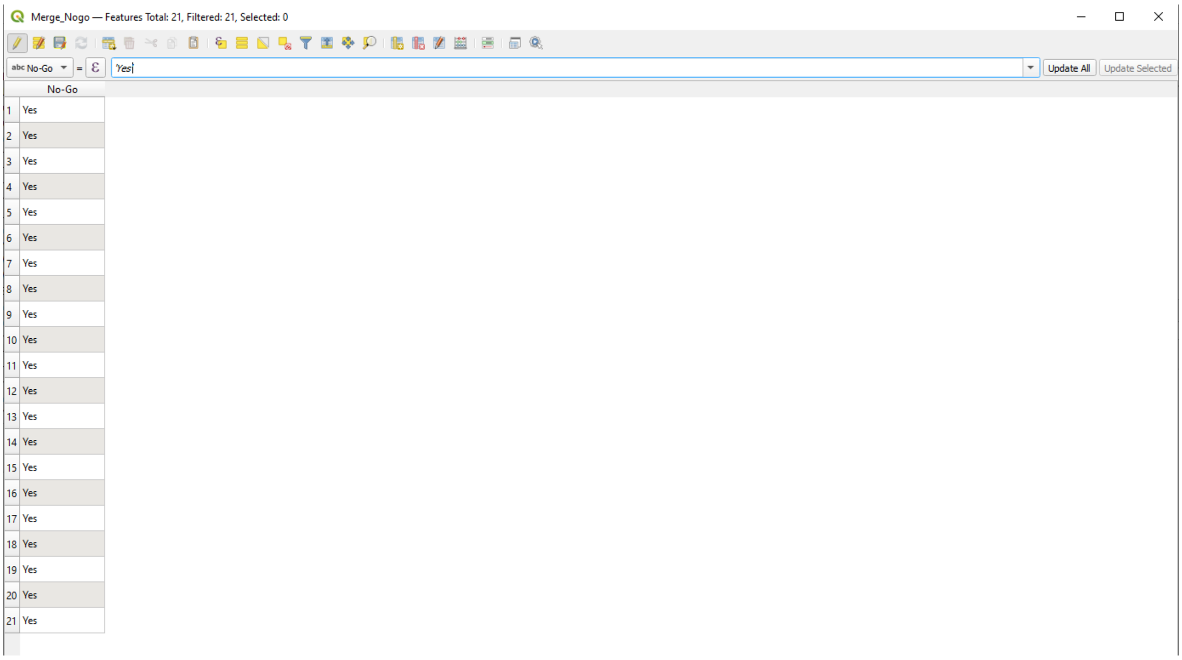
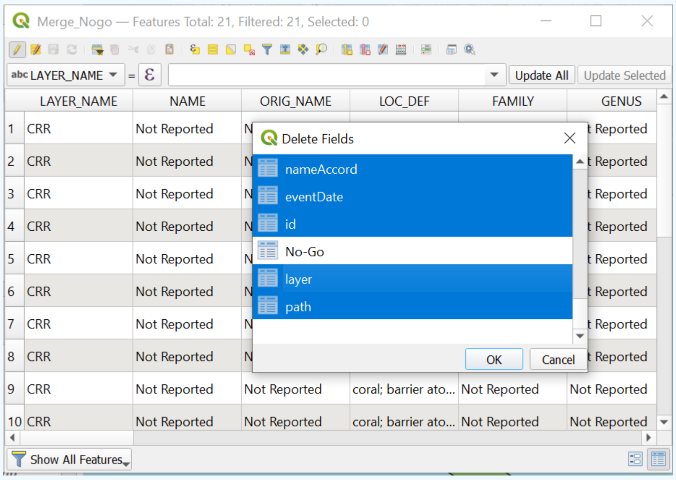


Figure 3.12: Attribute table for the 'no-go'-layer

Tip:

You may want to delete unnecessary fields in the attribute table.

To do so, open the **attribute table** and delete the fields you do not need by enabling editing  and clicking on the **delete field** option . Choose the fields you want to delete and click **ok**.



4.3.3 Creating one Layer Combining all Areas to Negotiate

Repeat the steps from section 2.2 for all the negotiable areas. Merge the layers, add a new table with string (text) and assign all features the value 'Yes'.

4.4 Step 3. Unify the Data-groups

Use the **union tool** to combine the three layers we created in **step 3**. The resulting output is the final layer that only needs a few more adjustments.

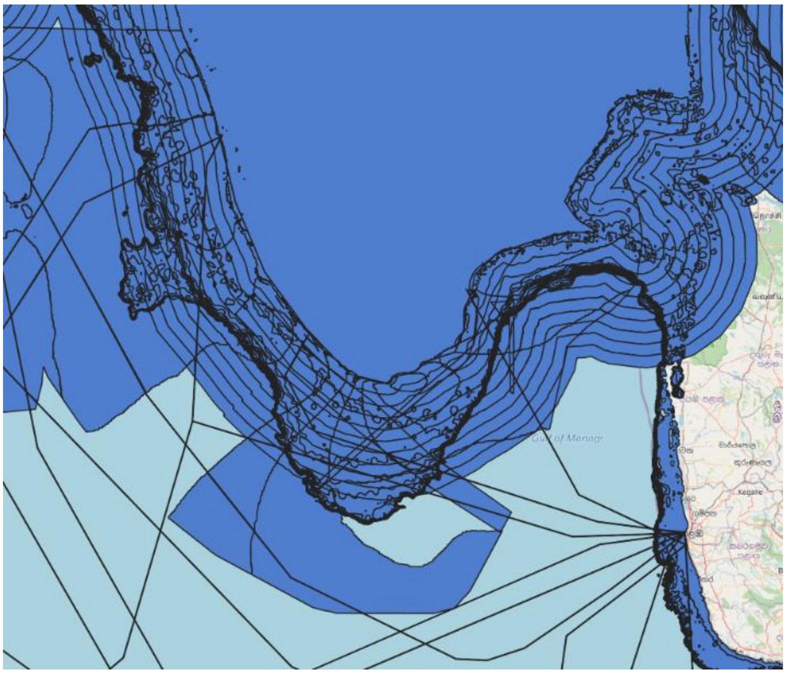


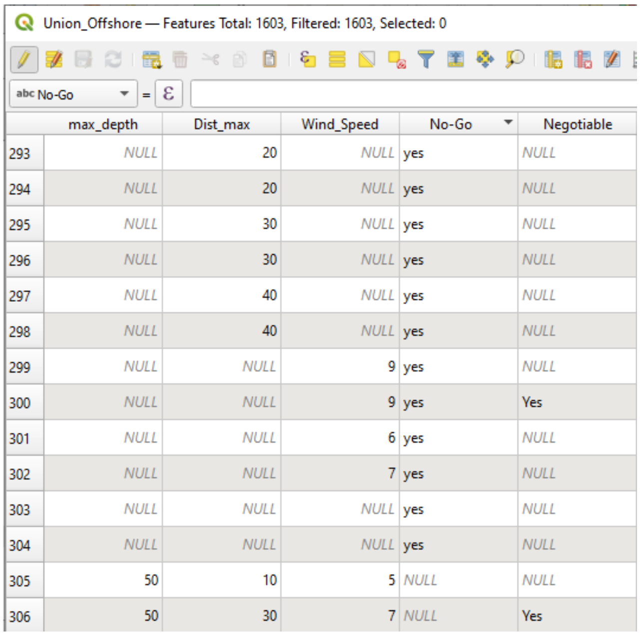
Figure 3.13: Example of the final output layer with all data unified

In the attribute table, **delete** all unnecessary fields.

4.5 Step 4. NULL Values to 'No' Values

The attribute table of the final output layer contains attribute values from all three data-groups; physical limitations, wind speed, distance, status on whether the area is a no-go area, negotiable or available.

If an area in the final output layer does not contain a no-go or negotiable area the field in the attribute table will show a **NULL value**, see the figure below. We want to change the NULL values to the status **'No'**



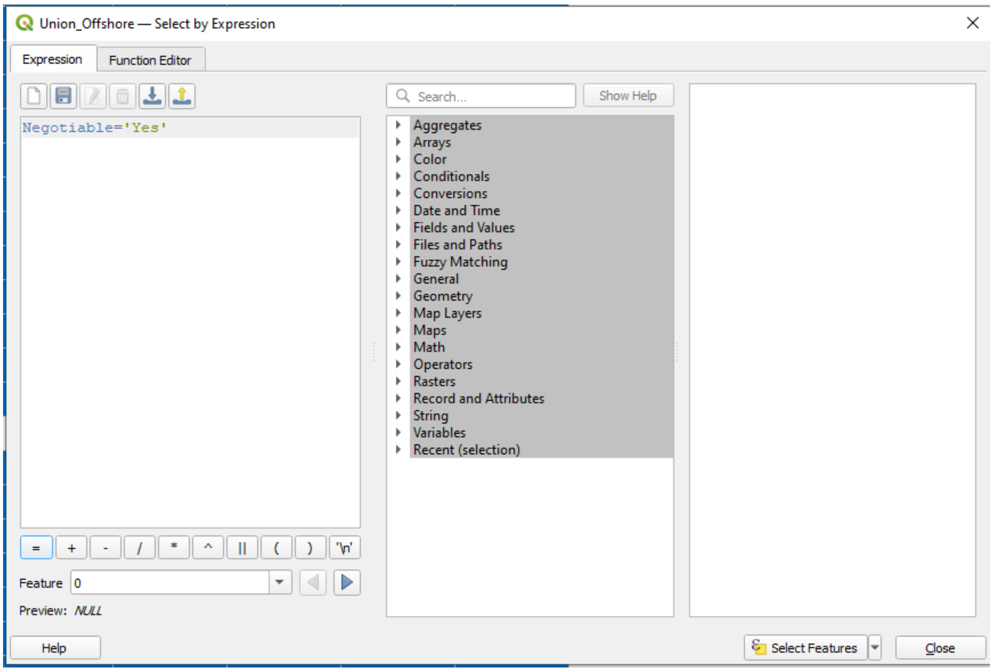
Union_Offshore — Features Total: 1603, Filtered: 1603, Selected: 0

	max_depth	Dist_max	Wind_Speed	No-Go	Negotiable
293	NULL	20	NULL	yes	NULL
294	NULL	20	NULL	yes	NULL
295	NULL	30	NULL	yes	NULL
296	NULL	30	NULL	yes	NULL
297	NULL	40	NULL	yes	NULL
298	NULL	40	NULL	yes	NULL
299	NULL	NULL	9	yes	NULL
300	NULL	NULL	9	yes	Yes
301	NULL	NULL	6	yes	NULL
302	NULL	NULL	7	yes	NULL
303	NULL	NULL	NULL	yes	NULL
304	NULL	NULL	NULL	yes	NULL
305	50	10	5	NULL	NULL
306	50	30	7	NULL	Yes

3.14: Attribute table of the final output layer

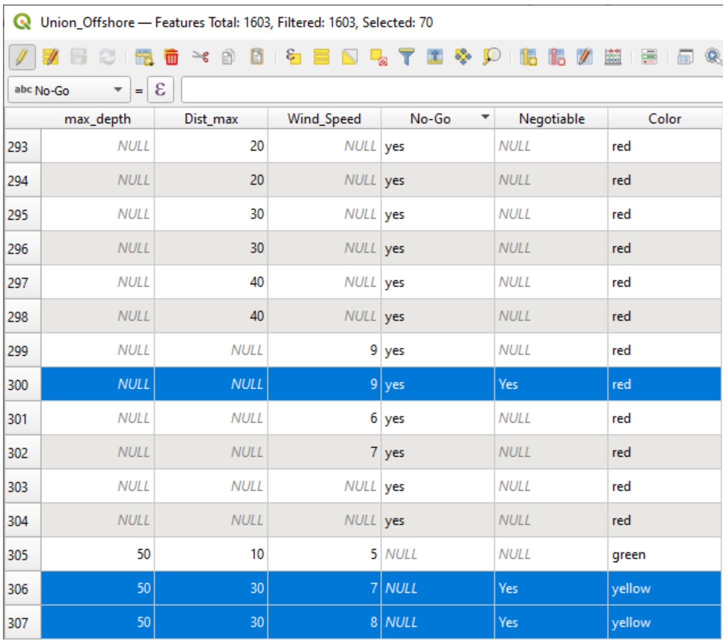
Open the attribute table and **enable editing**, click on **select features by expression**. A window should pop up where you can write an expression that enables you to select specific values. To do so write an expression like the one exemplified in figure 2.15.

The expression should include your field name (e.g. Negotiable) an operator (e.g. =) and the value you want it to select (e.g. 'Yes'). Click **Select Features** in the bottom right.



2.15: 'Select By Expression' window

All the 'Yes' values should now be selected, see figure 2.16.



Union_Offshore — Features Total: 1603, Filtered: 1603, Selected: 70

	max_depth	Dist_max	Wind_Speed	No-Go	Negotiable	Color
293	NULL	20	NULL	yes	NULL	red
294	NULL	20	NULL	yes	NULL	red
295	NULL	30	NULL	yes	NULL	red
296	NULL	30	NULL	yes	NULL	red
297	NULL	40	NULL	yes	NULL	red
298	NULL	40	NULL	yes	NULL	red
299	NULL	NULL	9	yes	NULL	red
300	NULL	NULL	9	yes	Yes	red
301	NULL	NULL	6	yes	NULL	red
302	NULL	NULL	7	yes	NULL	red
303	NULL	NULL	NULL	yes	NULL	red
304	NULL	NULL	NULL	yes	NULL	red
305	50	10	5	NULL	NULL	green
306	50	30	7	NULL	Yes	yellow
307	50	30	8	NULL	Yes	yellow

2.16: Attribute table of the final output layer with selected 'Yes' values (Negotiable field)

In the attribute table, click on invert selection  and your selection should switch from slecting 'Yes' values to selcting NULL values. Use the expression dialog panel to assign the selected features the value 'No'. Make sure to click **Update Selected** **instead** of **Update All**.

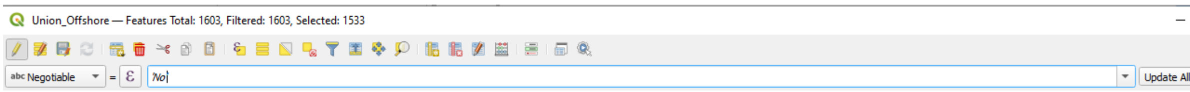


Figure 2.17: Expression dialog panel in the attribute table

4.6 Step 5. Classify the Results

Lastly, we want to select the attributes that fit with the color scheme in table 2. In the *processing toolbox* search for **select by attributes** and open the tool. Select all No-Go areas by using your final output layer as **input layer** and the **selection attribute** as your field that contains your no-go values. Choose the operator "=" and the value = 'Yes'. Click **run** and close the tool.

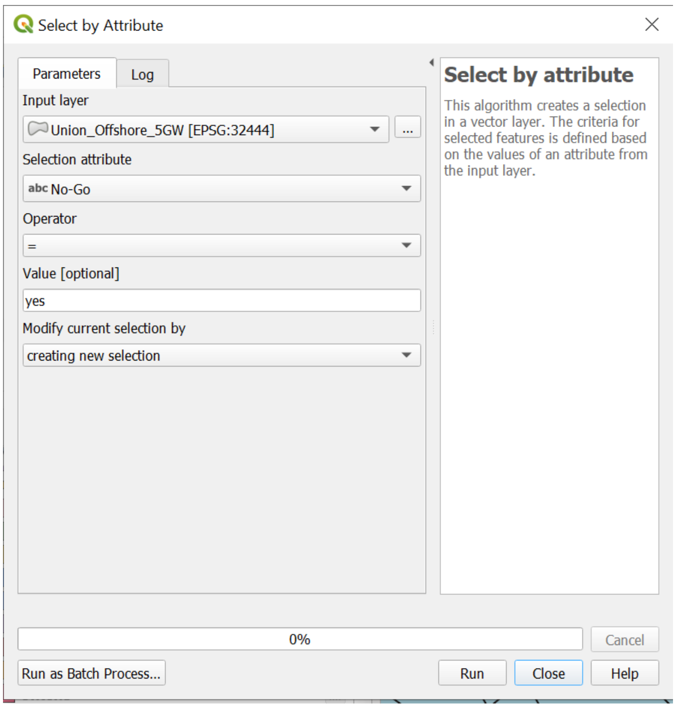


Figure 2.18: 'Select by Attribute' window in QGIS

Your selected values should be visible. Open the **attribute table** and **add a new field** where you specify the subgroup i.e. the color scheme, see table 2.1. Use the **expression dialog panel** to choose the newly created field and classify the selected features as ‘red’, since they are the no-go areas.

Union_Offshore — Features Total: 1603, Filtered: 1603, Selected: 0

	max_depth	Dist_max	Wind_Speed	No-Go	Negotiable	Color
1429	50	10	NULL	No	No	green
1430	50	30	NULL	No	No	green
1431	50	70	NULL	No	No	green
1432	50	80	NULL	No	No	green
1433	50	90	NULL	No	No	green
1434	50	100	NULL	No	No	green
1435	50	10	NULL	No	No	green
1436	50	20	NULL	No	No	green
1437	50	30	NULL	No	No	green
1438	50	40	NULL	No	No	green
1439	50	10	NULL	No	No	green
1440	50	20	NULL	No	No	green
1441	50	30	NULL	No	No	green
1442	50	40	NULL	No	No	green

Figure 2.19: Attribute table of the final output layer with all assigned values

Now, select all **available areas** (green) and classify the selected features ‘green’ in the **Color** field. Repeat for **negotiable areas** (yellow) and **limited negotiable areas** (orange).

Open the layer properties → symbology and classify the four categories according to the color scheme in table 2. In the upper most panel set the **classification scheme** to “Categorized”. Set **value** to the attribute field with the color classifications you just created (green, yellow, orange and red). Click on classify and change the colors to the adjacent ones. Click **apply**.

Your map should now show all the areas classified by color, so it is easy to see which areas are available, negotiable or not available depending on the physical limitations and conflicting interests, see figure 2.10.

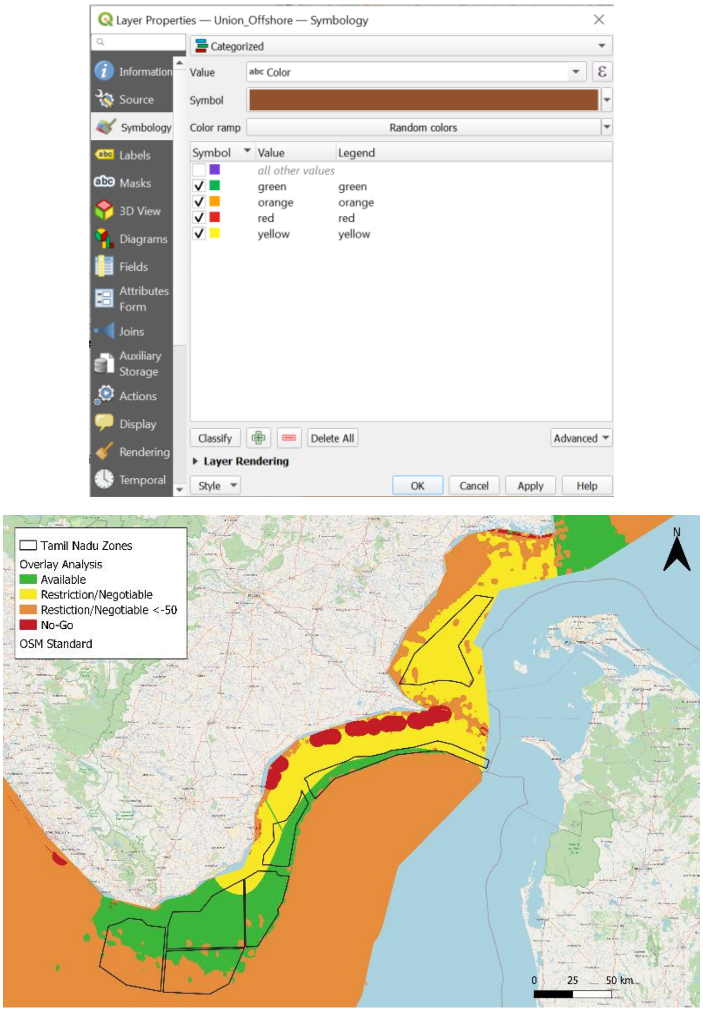


Figure 2.10: Layer properties window of the final output layer (left) and the color scheme applied on the final output layer

Appendix B:

Concept / System Description of an Offshore Wind Farm

18 November 2022

Centre of Excellence
for Offshore Wind and Renewable Energy

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1. Offshore project elements

The physical elements in an offshore wind power project comprises:

- Wind turbine generators (WTGs)
- Foundations
- Offshore substation(s)
- Offshore cables (export and array)

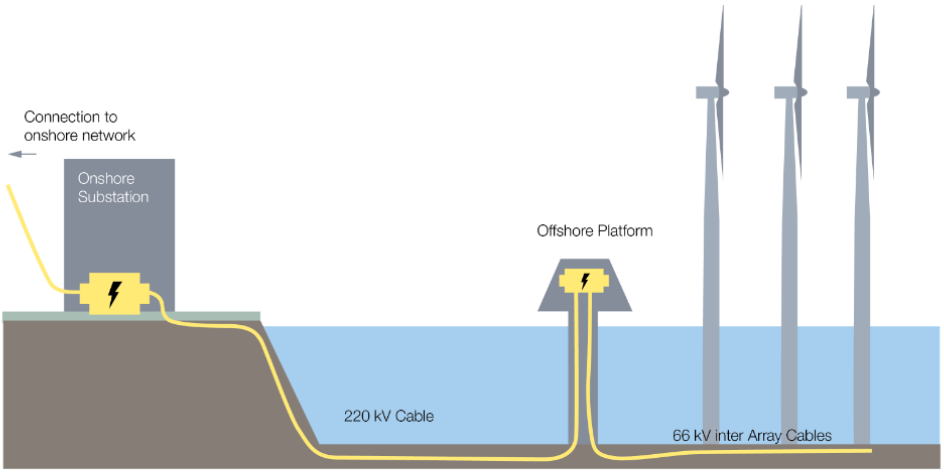

Figure 1-1| Overview of the physical elements of an offshore wind farm (COWI, 2021)

As the figure shows, an offshore project also comprises onshore elements. However, in this report, focus is on the offshore elements as listed above.

2. Wind Turbine

The standard offshore turbine is a horizontal-axis, three-bladed machine, that captures incident wind and uses it to turn a generator that produces electricity. The basic layout of a wind turbine and its main components are presented in Figure 2-1 below.

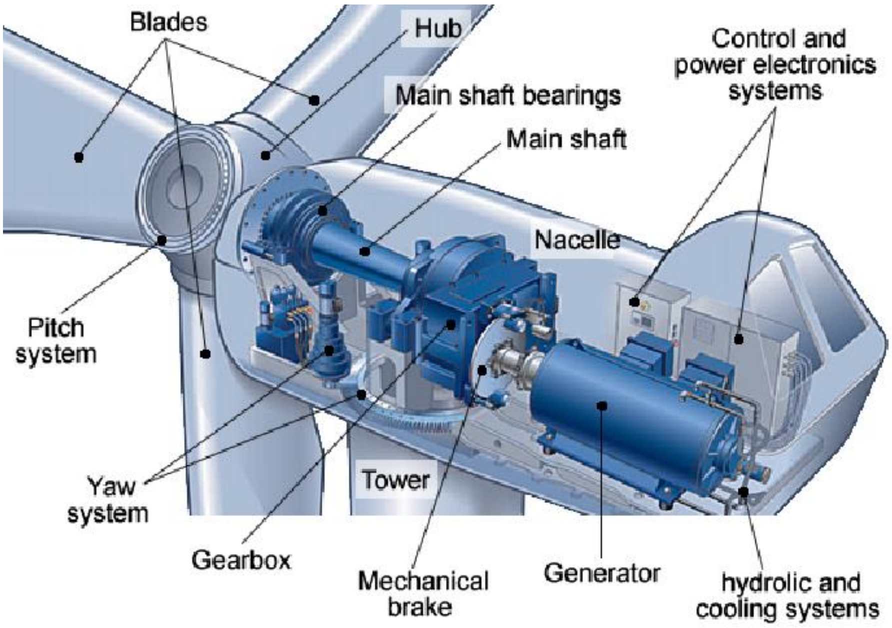

Figure 2-1 | Main components in an offshore wind turbine (Tchakoua, Wamkeue, & Theubou, 2013) in the concept/system sub-report)

Selecting the correct offshore foundation type requires a significant understanding of technical, financial as well as environmental project characteristics and requirements. Geophysical and geotechnical investigations along with ground scans are undertaken in order to understand the soil quality and to determine any stratification along with locating any objects in the installation area. These tasks are considered fundamental measures prior to the design of the foundation structure.

Foundation design is one of the most critical stages in offshore wind power projects due to the complexity of the investigations and the relevance for the stability of the wind turbine. Several different foundation designs are available. The figure below presents the variety of fixed bottom designs.

Figure 2-2| Overview of fixed bottom design concepts (COWI, 2021)

Floating foundations are proven technology in the oil and gas industry but are only just starting to be applied to offshore wind turbines. There are various technologies that have been adapted for wind turbines as illustrated in Figure 2-3. The technology has only been employed on prototypes and demonstration scale projects to date.

Figure 2-3| Visualization of different types of floating foundations (NREL, u.d.) in the concept/system sub-report)

3. Offshore substation

An offshore substation (OSS) collects the power generated by the wind turbines in the wind farm and steps the voltage up for transmission to shore and power grid, e.g., 33 kV or 66 kV to 132 kV or 220 kV. The offshore substation (OSS) contains high voltage transformers, switchgear, converters, grid stabilisers such as capacitor banks and shunt reactors, cooling, fire suppression and other equipment and are a critical piece of infrastructure in modern offshore wind farms. Like wind turbine support structures, the OSS is designed to withstand the site-specific offshore conditions and generally located within the wind farm itself. The OSS consists of a topside, where all the electrical equipment is contained, and a support structure, as illustrated in Figure 3-1.

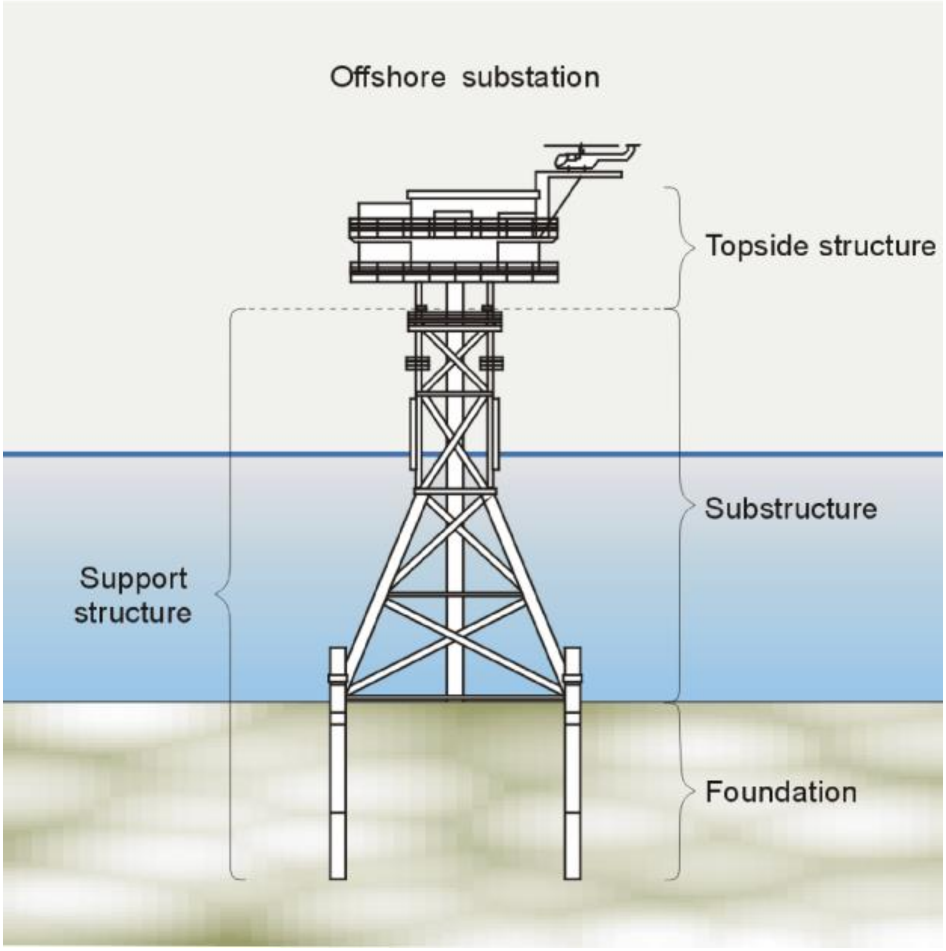

Figure 3-1 | A schematic of a typical offshore substation (Robak & Raczkowski, 2018) in the concept/system sub-report)

4. Offshore cables

Offshore submarine cables consist of both inter-array cables, which connect wind turbines in the wind farm together into a series of strings and deliver their power to an offshore substation, and export cables, which transmit the combined power of the wind farm from the OSS to shore.

A typical electrical system configuration for an offshore wind farm including an Offshore Substation (OSS) is shown in the figure below.

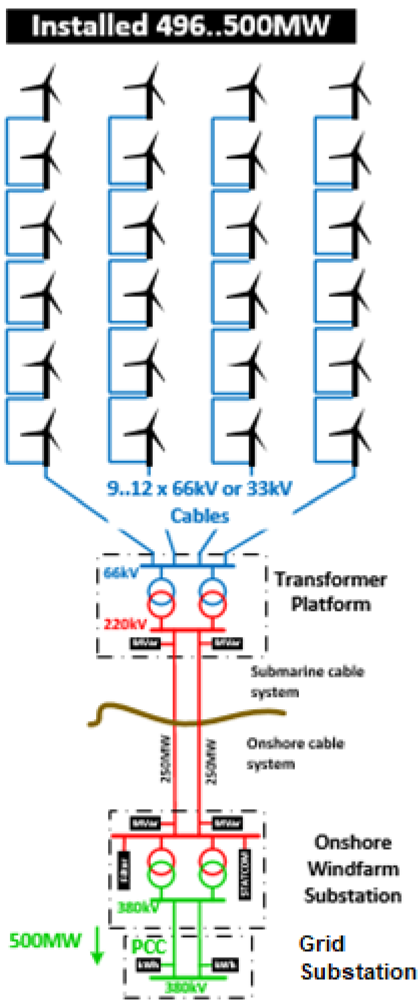

Figure 4-1 | Typical Transmission System with Offshore Substation (COWI, 2021)

It is typical for subsea cables to be buried in the seabed, but there are a variety of burial strategies that can be considered depending on the soil and sediment conditions at site.

5. Logistics and infrastructure

5.1 Harbour facilities

Due to their size and weight, most offshore wind farm components are manufactured and fabricated at waterfront facilities. Manufacturing can either include full assembly of main components, or be limited to preassembly activities, such as arrangement of converters, switchgear, etc. on tower internal platforms. Storage and staging areas are needed for loadout, and construction activity may consist of pier or wharf structures suitable for the components being handled. In an offshore wind farm, storage and staging areas are needed to handle blades, nacelles, hubs, towers, foundations and other components, but also small miscellaneous parts and tools needed for assembly.

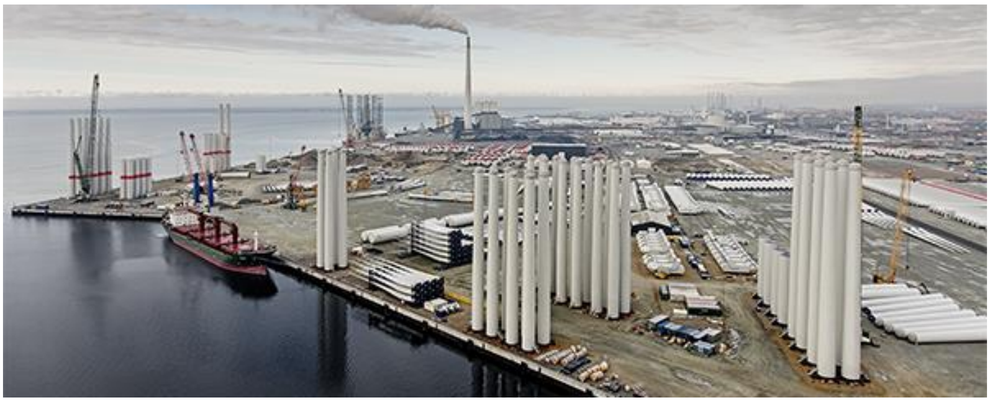

Figure 5-1 | Port of Esbjerg in Denmark load out facilities (Esberg)

In addition to components, harbour facilities must be able to accommodate berthing of installation vessels which transport the foundations and the wind turbine components to the site. During the construction period a port with enough storage space and crane capacity must be available to handle and move the foundations and the wind turbine components both in upland areas during load-out and transport preparation.

5.2 Vessels

Several different kinds of vessels are used for both installation and operation of an offshore wind farm.

Installation will normally make use of a jack-up vessel, a cable laying vessel and a series of transportation and feeder barges. The jack-up vessel is designed to lift itself out of the water to create a stable platform for heavy lifts and bottom fixed installations. This stability allows for lifting in more various wind and sea state conditions, although exact wind speed and wave height criteria for installations will be vessel dependent and dependent on component weight and crane capacity. However, floating installation vessels are also available in the market. These vessels may be used in areas where jack-up is challenging for instance in case of soft seabed conditions.

Figure 5-2 | Voltaire jack-up vessel (Jan De NUl Group)

Cable laying vessels both carries the cable(s) and can lay the cables.

Figure 5-3 | Cable laying vessel Isaac Newton (Jan De Nul Group, n.d.)

For the operation phase, Crew Transfer Vessels (CTVs) and Offshore Service Vessels (OSVs) support routine operation and maintenance (O&M) over the life of the wind farm. CTVs and OSVs may transport technicians and equipment, minor replacement components, and lubricants to and from the wind farm.

As wind farms are moving further offshore, Service Operation Vessels (SOVs) are becoming a popular choice for servicing. These vessels typically have advanced motion compensation features on cranes and/or walking gangways which allow safe access to turbines when completing work in rougher seas. In addition, a SOV typically has sleeping and living quarters, housing over a hundred people for weeks at a time. The ability to store to work and to live on the vessel reduces back-and-forth travel during regular or extended maintenance campaigns, or when serving multiple wind farms in a single area.

Figure 5-4 | Service Operation Vessel used by Siemens for servicing offshore wind farms (Esvagt, n.d.)

6. Wind resource and layout considerations

Wind resource assessment is less complex offshore than onshore, because there are limited topographic effects and obstacles offshore that need to be considered. However, in offshore wind resource assessment, special attention shall be made to:

- Wake loss modelling – both within and in between wind farms
- Blockage effects[1] – both in a wind turbine and in a wind farm level

Offshore wind assessment studies must still account for factors like the wind shear, atmospheric stability, local sea/land breeze effects, wave dependent roughness and more. In addition, the following considerations are fundamentals for estimating the wind resource and the potential energy yield at a given site:

- Turbine hub height
- Mesoscale modelling in consideration of coastal impact
- On-Site measurements and historical measurements nearby/on-site
- Wind farm layout
- Uncertainties in measurements and calculations.

[1] The blockage effect arises from the wind slowing down as it approaches the wind turbines. There is an individual blockage effect for every turbine position and a global effect for the whole wind farm, which is larger than the sum of the individual effects.

From an energy perspective the optimised wind farm layout should maximise energy production. However, there are technical and regulatory constraints that often pose limitations and the MW density for offshore wind farms often varies between 4.5 to 10 MW per square km.

Land-use and sensitive environmental areas such as marine paths, protected areas, marine sanctuaries, wildlife refuges, fishing zones, shipping and towing lanes, and offshore platforms and pipelines, etc., may impact the layout. Proper identification and consideration of the impacts require active stakeholder outreach to industry groups, governmental agencies, NGO's and public/private citizens who may be affected by the development.