Maritime Spatial Planning for offshore wind farms in Tamil Nadu

24 February 2023

Centre of Excellence
for Offshore Wind and Renewable Energy

Copyright

Disclaimer

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 the Ministry of New and Renewable Energy (MNRE) and the National Institute of 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 practices 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.

Acknowledgements

This report is prepared as part of the Centre of Excellence for Offshore Wind and Renewable Energy under the Strategic Sector Cooperation on offshore wind and the Green Strategic Partnership between India and Denmark. The work has been supported by COWI, the World Bank ESMAP program and the Biodiversity Consultancy. We would like to acknowledge all the stakeholders in India and abroad who contributed to this marine spatial planning report by providing technical data, reviewing chapters and participating in workshops. Without these contributions, it would not be possible to produce this publication.

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

Table of Contents

Figures

Tables

Abbreviations

AIS	Automatic Identification System
ATS	Air Traffic Control
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

India is blessed with a long coastline of about 7600 km and has good prospects of harnessing offshore wind energy. It is envisaged that offshore wind energy will play a significant role in meeting renewable energy targets and needs of the future demand.

To ensure the best possible use of the marine space in an efficient, safe and sustainable way, the Ministry of New and Renewable (MNRE) and the National Institute of Wind Energy (NIWE) together with the Danish Energy Agency (DEA), have been carrying out a Maritime Spatial Planning (MSP) project in the states of Tamil Nadu and Gujarat. The Maritime Spatial Planning project builds on the existing work carried out in the FOWIND and FOWPI projects to refine and make further recommendations supporting a clear and transparent future planning and collaborative balance of interests, which will encourage investments in offshore wind.

This report 'Maritime Spatial Planning for offshore wind farms in Tamil Nadu' focuses on the Tamil Nadu 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 conceptual layouts of the selected zones off the coast of Tamil Nadu for further stakeholder consultations and inputs. The report will further provide a specification of the priority 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 the most suitable areas for prioritising offshore wind farm development, considering various physical, environmental, and social parameters.

In relation to the rough screening, Figure 0.1 below summarizes and illustrates the considerations made during the rough screening off the coast of Tamil Nadu and presents the overview of potential constraints.

In conclusion, the offshore wind development zones in Tamil Nadu (zones B, D, E and G) offers some of the best available sites for offshore wind development projects within the country, with relatively high wind speeds, favourable seabed depths and limited conflicts with environmental and social receptors. Based on the rough screening, offshore wind development within these zones can be prioritised compared to zones A, C and F.

Specifically, zone F, which experiences low wind speeds (<7.0 m/s) and shallow water depths (<10.0m), is not conducive to large-scale offshore wind farm development. Being located within an Important Marine Mammal Area (IMMA), zone F would also require further detailed assessment, based on various environmental surveys to evaluate the viability of zone F for offshore wind farm development.

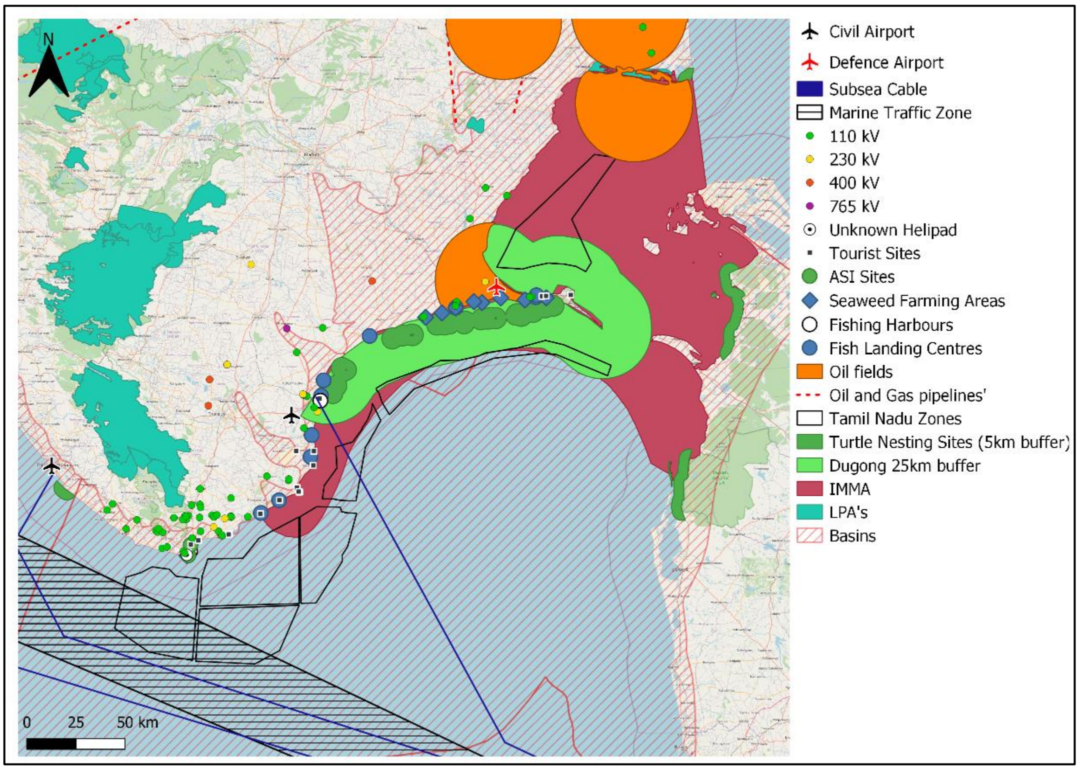


Figure 0.1 - Rough screening of coastal area in Tamil Nadu

Fine screening was carried out focusing on the following elements:

- Marine traffic;
- Wind climate;
- Seabed screening;
- Port and logistic infrastructure.

The rough and further fine screening conducted identified marine traffic as a key constraint and significant competing users within the OWF Zones in Tamil Nadu. This potential conflict was further analysed and has led to narrowing down the available area to a shortlisted site area measuring ~3600 km², while adopting the principles of co-existence with competing users.

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

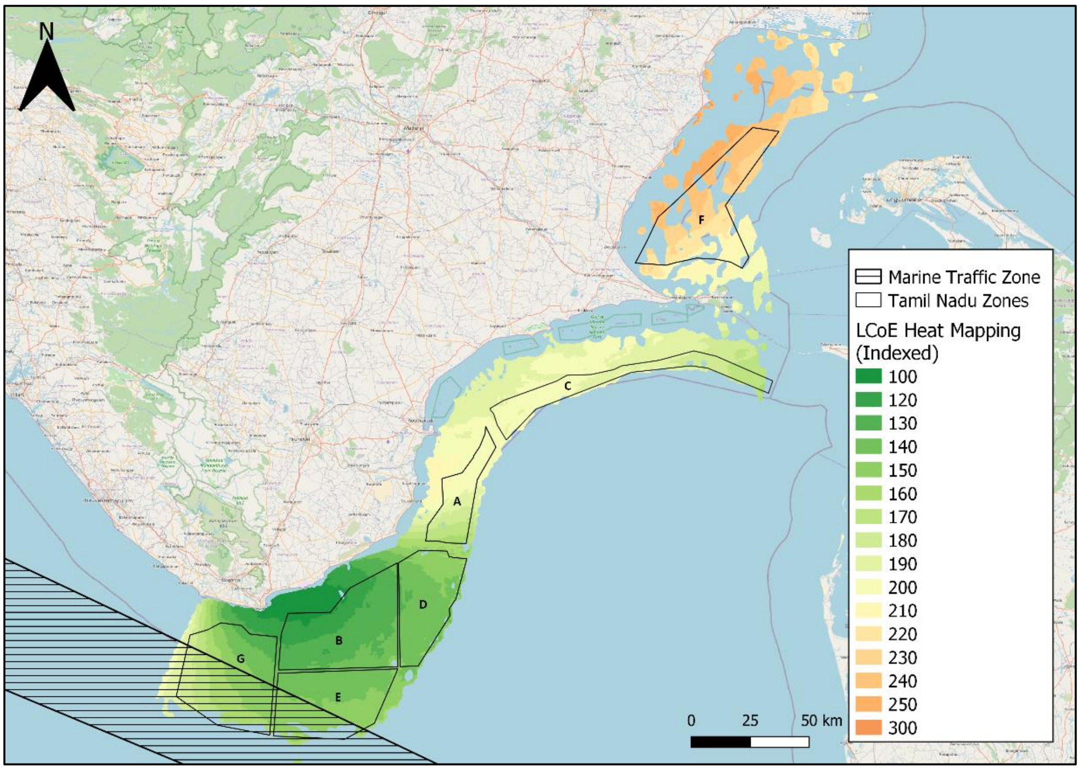


Figure 0.2 - LCoE Heat Map of Tamil Nadu coast

As part of the fine screening a further technical analysis was carried out to formulate the basis for conceptual planning of the shortlisted 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 the electrical power system as a limiting factor for individual wind farms within the shortlisted sites;
- Turbine suitability;
- External wake loss and separation distance between the plots; and
- Electrical power systems and export configuration.

The above considerations provided inputs to a preliminary conceptual plan (illustrated in Figure 0.3) and are prepared for consultation with Indian Stakeholders and alignment on the planning principles, which aims to support the overall Indian strategy for the establishment of offshore wind energy projects.

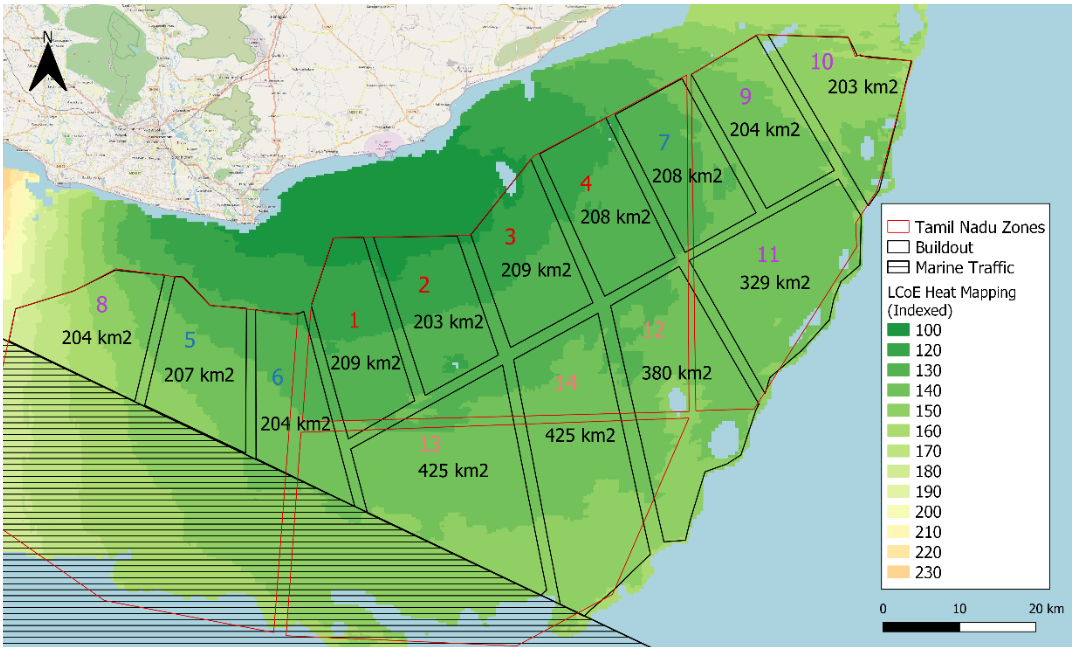


Figure 0.3 –The conceptual plan for Tamil Nadu area

Within the offshore wind zones, selected environmental and human use parameters were mapped in GIS, to the extent possible and given the information available. It is 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.

The information and data gathering will illustrate and qualify the potential constraints and conflicts, but to attain the objective of the marine spatial planning exercise, 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 plans. Addressing spatial conflicts is essential to transitioning 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 Tamil Nadu:

- 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 maintain and further obtain feedback on the proposed traffic management planning and separation schemes.

- Transmission Grid and electrical system: The available information in the public domain only allows for a high-level screening of available grid connections and rated capacities of potential points of interconnection (substations). A close liaison with Transmission System Operators (PowerGrid and TANGEDCO) is therefore essential to fully understand the impact on grid due to power connection by OWF and evaluate / consider options for grid reinforcement.

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

- Fisheries: The analysis established that the area off the coast of Tamil Nadu is one of the most frequented areas used by local fishermen. To this end, further liaison with relevant government ministries and cooperation with fishermen is strongly recommended to fully understand the constraints and allow for planning for co-existence (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 Tamil Nadu, considering dynamic and evolving nature of defence requirements, it is recommend that a close liaison is maintained with relevant authorities to understand potential constraints / conflict with future offshore wind farm planning.

As is the case in other markets, it would make sense to establish a certain governance and structure for the engagement between the relevant parties in an Indian context. As an example, an Indian maritime spatial planning committee could be established consisting of the various institutional stakeholders to ensure the continuous coordination, dialogue and engagement across the various sectors to further support and guide the ongoing maritime spatial planning process.

1 Introduction

India and Denmark have been cooperating on developing relevant policies, strategies, and solutions to enable a low carbon transition of the Indian energy sector since 2018. The government-to-government collaboration aims at making relevant Danish experience available 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 the Ministry of New and Renewable Energy (MNRE) in its work for the implementation of 30 GW offshore wind by 2030.

Marine Spatial Planning is part of this cooperation specifically aiming at identifying the best areas to develop offshore wind projects highlighting the potential benefits and risks. As part of the marine spatial planning project the following output and deliverables have been produced:

- Maritime Spatial Planning for offshore wind farms in Tamil Nadu
- Maritime Spatial Planning for offshore wind farms in Gujarat
- Appendix A: GIS guide combined with the description of methodology of rough and fine screening
- Appendix B: Concept / system description of an offshore wind farm
- Appendix C: Technical Note on Marine Traffic Assessment in Tamil Nadu
- Appendix D: Technical Note on Electrical systems in Tamil Nadu
- Appendix E: Maritime Spatial Planning for offshore wind in India – Overview of engagement with Indian stakeholders

The main objective of the this MSP project is to identify the most suitable areas 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 areas and project sites for deployment of offshore wind have been identified via maritime spatial planning including a rough and fine screening.

This report focuses on Tamil Nadu and presents the importance of marine spatial planning in building up a pipeline of projects. Besides describing the screening methodology, the report presents the conceptual plan for the selected zones off the coast of Tamil Nadu. It is very import to emphasize the importance of stakeholder consultations and input as an essential part of marine spatial planning and this report can be seen as an input to this further consultation and dialogue with the various relevant stakeholders to attain transition from theoretical to actual offshore wind projects.

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 this knowledge 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 projects within the identified wind zones of Tamil Nadu to support the overall target of 30 GW by 2030.

1.2 The Study Area

The Facilitating Offshore Wind in India report (FOWIND, 2015) identified eight (8) zones (Zone A, B, C, D, E, F, G & H) as potential offshore wind development zones in the southern coast of Tamil Nadu.

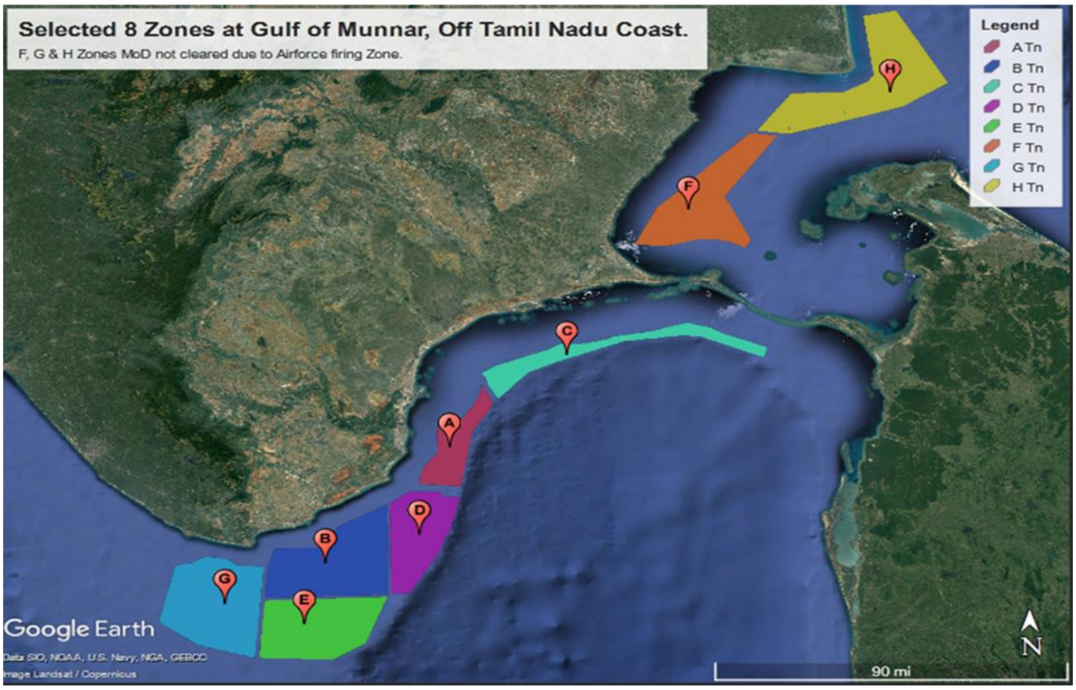


Figure 1.1 – Demarcated offshore wind energy zones at Tamil Nadu

Zone H is assessed to be not suitable for offshore wind development due to conflict of interest with the Ministry of Defence. Therefore, zone H is not considered as being part of the MSP process, and in this report the focus will only consider zones A, B, C, D, E, F and G.

2 Marine Spatial Planning (MSP)

Maritime spatial planning is an area which needs special attention and cooperation across various government institutions. Even though the ocean seems an open and eligible space, there are quite a lot of different interests which must be considered before engaging in planning specific projects.

Figure 2.1 - Illustration of maritime interests (Forum, 2021)

A maritime spatial plan forms the basis for coordination of the many uses of the sea area and supports the conditions for sustainable growth.

The key benefits of maritime spatial planning include:

- Ensure human activities at sea take place in an efficient, safe and sustainable way
- Support long-term planning and political target setting
- Increased cross-function cooperation, reduction of conflicts between sectors and creation of synergies between different activities
- Encouragement of investments by creating predictability, transparency and clearer rules
- Protection and preservation of the environment through early identification of impact and opportunities for multiple use of space

A maritime spatial plan establishes which sea areas can be used for offshore wind, shipping, fishing, aquaculture, seabed mining and environmental protection. A maritime spatial plan also creates more safety for the maritime business and better predictability of the uses of the sea and the impact on marine eco systems.

India is already engaged in developing marine spatial plans and focusing on managing geospatial data and geospatial data services. An example of the focus on the management of geospatial data is the Guidelines for acquiring and producing Geospatial Data and Geospatial Data Services including Maps (source: DST F.No.SM/25/02/2020 (Part-I) dated 15th February, 2021). In these guidelines the importance of the blue economy in India is clearly recognized, where geospatial data will play an important role. The guidelines on Geospatial Data and Maps are Issued by the Department of Science and Technology (DST), who will be the single point of reference on the subject. DST will constitute a Geospatial Data Promotion and Development Committee with representations from relevant departments. The Committee's mandate will include promotion of activities related to collection, generation, preparation, dissemination, storage, publication, updating and/or digitization of Geospatial Data.

The Government of India notified a national offshore wind energy policy. As per policy, "Ministry of New and Renewable Energy will act as the nodal ministry for development of offshore wind energy in India and work in close coordination with other government entities for development and use of maritime space within the exclusive economic zone (EEZ) of the country and shall be responsible for overall monitoring of offshore wind energy development in the country. National Institute of Wind Energy (NIWE) will be the nodal agency to carryout resource assessment, surveys and studies in EEZ, demarcate blocks and facilitate developers for setting up offshore wind energy farms."

Another example is the Indo-Norway Integrated Ocean Initiative, where the two countries have decided to extend support for sustainable ocean resources utilization to advance economic and social development in coastal areas. The initiative, known as Marine Spatial Planning (MSP), will be implemented by the Ministry of Earth Sciences (MoES) through the National Centre for Coastal Research (NCCR) for India. The initiative initially focuses on developing a marine spatial planning framework for Puducherry and Lakshadweep. Both these areas are outside the current focal areas for offshore wind in Tamil Nadu and Gujarat. However, going forward it will be important to ensure proper alignment with any MSP being developed and not least to establish sound and robust coordination between government authorities with interests in marine activities.

2.1 Methodology

The focal point for this MSP project is to ensure the best possible use of the marine space in an efficient, safe and sustainable way. The National Institute of Wind Energy (NIWE) will be responsible for carrying out a Marine Spatial Plan focusing on the deployment of offshore wind. NIWE will also be the responsible institution responsible for the stage-I clearances and will be responsible for single window clearances for No Objection Certificates (NOCs) as required in accordance with the notified national offshore wind energy policy. The Marine Spatial Plan will build on the existing work done during the FOWIND project and refine it accordingly through engagement and dialogue with Indian Government authorities and stakeholders. This element is perceived crucial for balancing multi-interests at sea and developing solid conclusions in relation to offshore wind planning. The overall aim is to minimize risks and uncertainties for investors and encourage long-term investments.

Based on Pre-feasibility studies (FOWIND) and preliminary techno-economic analyses (FIMOI project, 2022) it appears that the identified zones off the coast of Tamil Nadu will be more suitable for offshore wind compared to the zones in Gujarat when comparing wind resource. This will provide a short-term build-out plan, before broadening the picture and focus on the longer-term implementation plan for offshore wind to meet the overall target of 30 GW by 2030.

MSP starts with a rough screening of the coastal area of Tamil Nadu with a focus on offshore wind zones identified in the pre-feasibility study report. At this stage of the process, parameters such as wind resources, bathymetry, environmental and social considerations are assessed to map the potential constraints in the whole area of interest. At the end of the rough screening process, exclusion and restriction zones as well as no-go areas are specified.

Besides the rough screening there is a focus on the fine screening, which includes a more in-depth analysis of constraints in the area. As a basis for selecting the most attractive sites the estimated Levelized Cost of Electricity (LCoE) is calculated and presented in form of heat maps. These maps are used for the conceptual plan and buildout considerations, which are aimed at creating the pipeline for offshore wind projects while optimizing the available space in the coastline of Tamil Nadu.

2.2 Rough Screening

Rough screening is carried out considering wind speeds above 7 m/s and water depths between 10-65 meters to identify the economically most viable areas for offshore wind development in Tamil Nadu. Besides the wind resource and water depths various environmental and social considerations will be described together with the grid and electrical infrastructure aspects.

Figure 2.2 below provides a simple heat map of India, which illustrates the wind speed and water depths in the offshore areas of Tamil Nadu and within the offshore wind farm zones.

The area off the coast and within the offshore wind farm zones is observed to be 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, except for zone F in which wind speed is seen to be less than 7 m/s.

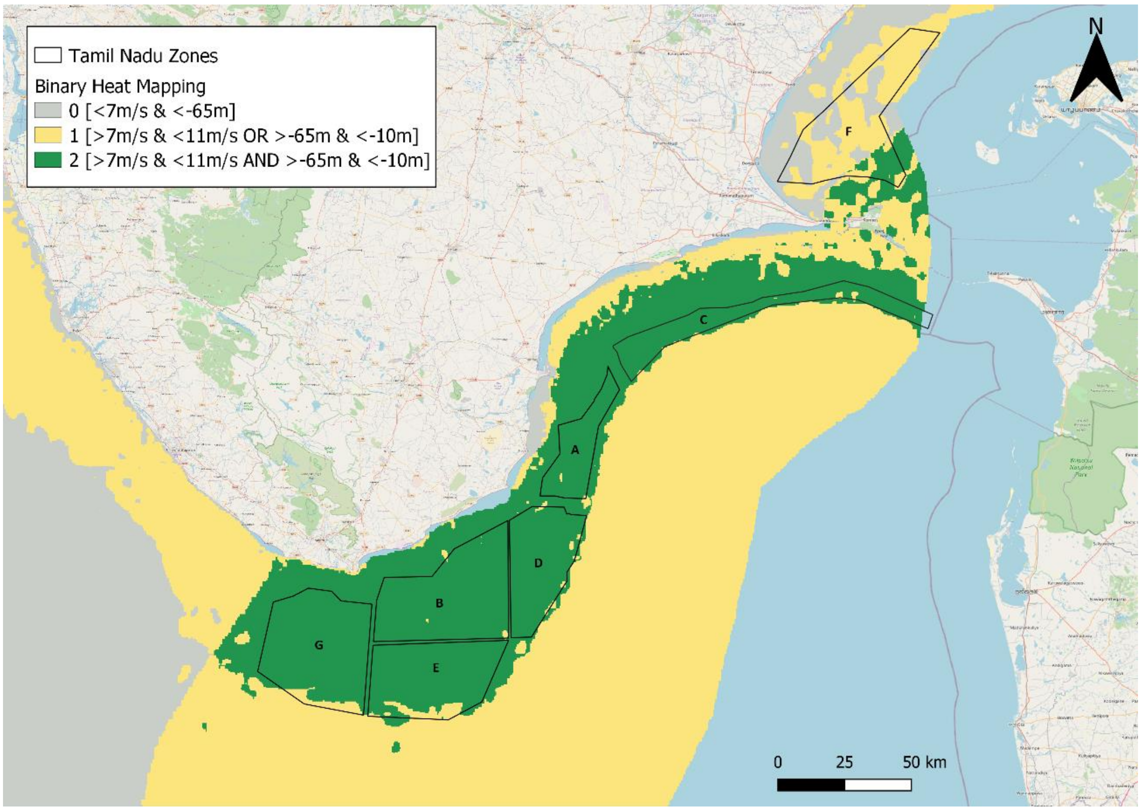


Figure 2.2- Binary heat map of India

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 reach up to ≤11.06 m/s. Specifically, wind speeds above 8 m/s are concentrated in the South Indian near- and offshore regions. The wind speed at the selected zones varies from 9 to 11m/s (see Figure 2.3).

Seasonal changes in wind direction and magnitude were not taken into consideration in the rough screening, however, are considered during the fine screening.

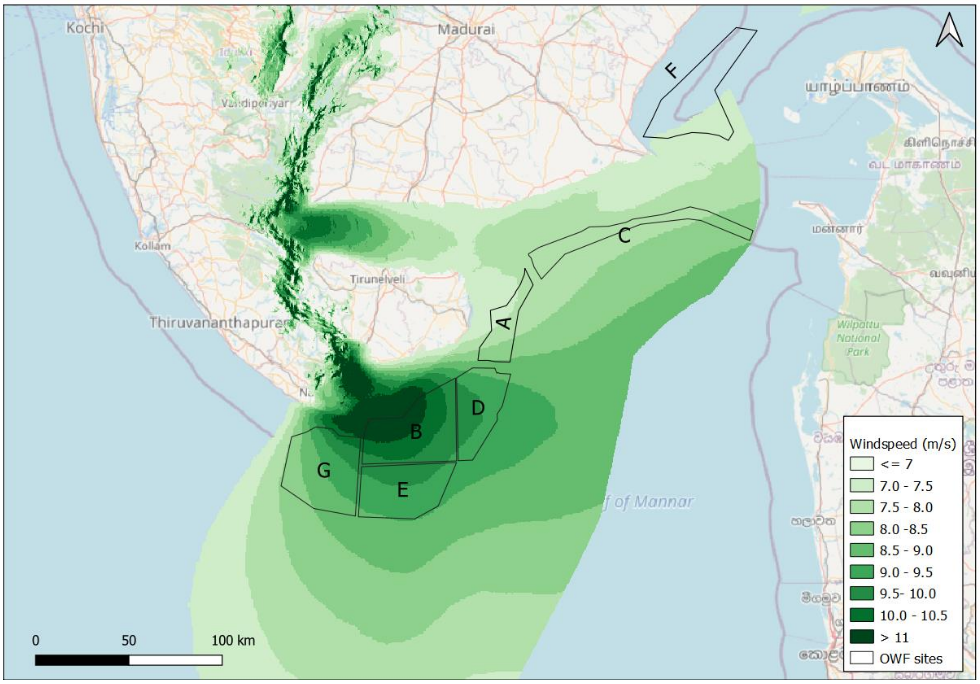


Figure 2.3 – Wind speed map of South India with speeds >7m/s, showing the selected zones (ESMAP, Global Wind Atlas , 2021)

2.2.2 Seabed Conditions

The rough screening considers bathymetry, water depth and seismic risks as the only parameters in relation to foundation conditions and costs from the seabed conditions perspective.

Figure 2.4 exemplifies water depths in the offshore areas near the southern region of Tamil Nadu that are between a minimum of 10m and a maximum of 65m. The reason for selecting this range is to fulfil the water depth criteria for fixed bottom foundation design considering the best practices and current applications in other wind farms around the world. Therefore areas in zone F, which are observed to have water depths less than 10m, are not considered to be ideally suited for development of offshore windfarms, especially for installation of fixed foundations.

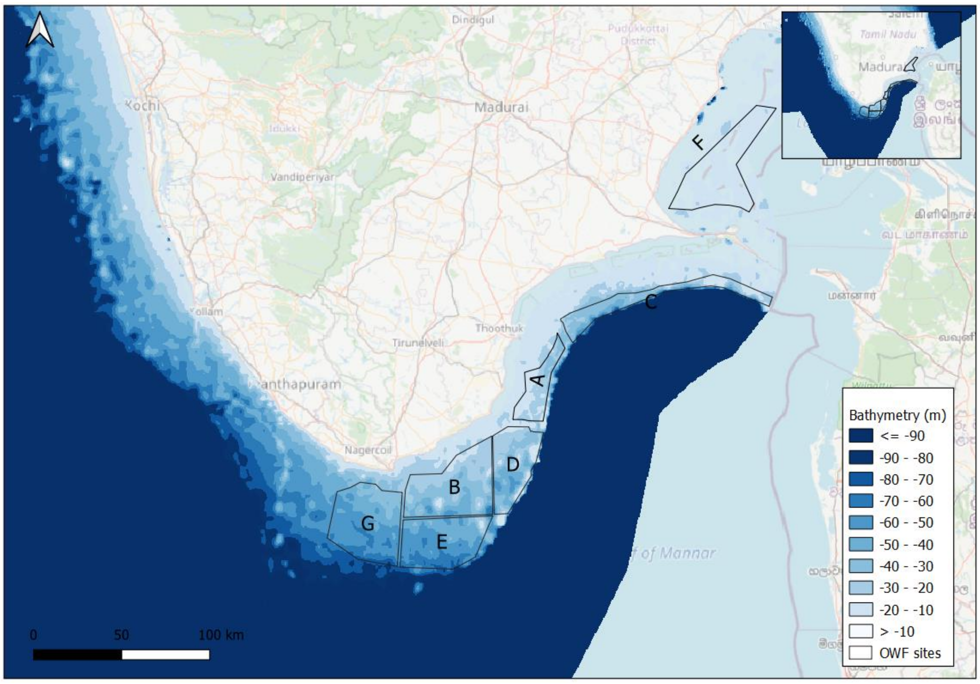


Figure 2.4- Bathymetry map of South India showing the selected zones (ESMAP, Global Wind Atlas , 2021)

According to the GSHAP data, the state of Tamil Nadu falls mostly in a region of low seismic hazard with the exception of western border areas that are located in a low to moderate hazard zone. Historically, parts of the Tamil Nadu and Puducherry region have experienced seismic activity in the M5.0 range[1]. Further analysis of the seabed conditions has been made during fine screening, details of which are provided in section 2.3.2 of this report.

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 GIS files received from The Biodiversity Consultants (TBC) commissioned by the World Bank Group to provide information on the key biodiversity areas. 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.

[1] Amateur Seismic centre, Pune, 2022, GSHAP Hazard maps, Tamil Nadu and Puducherry (http://asc-india.org/maps/hazard/haz-tamil-nadu.htm).

Based on the information presented, exclusion and restriction zones have been identified (section 2.2.3.8) which formed the basis for further consideration during the fine screening and 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 (IBAs) and Alliance for Zero Extinction (AZE) sites, Ecologically or Biologically Significant Marine Areas (EBSAs) and Important Marine Mammal Areas (IMMAs).

Gulf of Mannar Marine National Park to the northeast of the zones is one of the designated (marine) national parks of the country wherein no human activity is permitted, except those permitted by Chief Wildlife Warden for activities such as eco-tourism.

Figure 2.5 illustrates the Legally Protected Areas (LPA's) around the offshore wind farm zones.

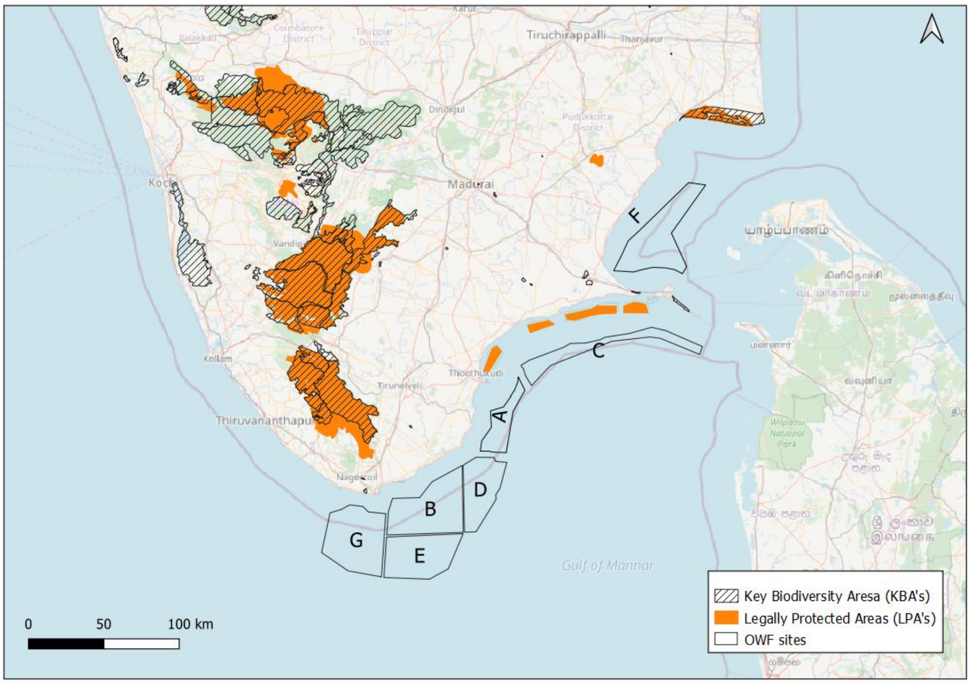


Figure 2.5 - Legally Protected Areas around selected zones (COWI, 2021)

2.2.3.2 Marine Mammals and Turtles

The Gulf of Mannar and Palk Bay IMMA (Marine Mammal Protected Areas Task Force 2021a) in Tamil Nadu are important for Dugong as well as 15 species of cetaceans including Blue Whales. Figure 2.6 illustrates key habitats for marine mammals and turtles around the selected 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 Important Marine Mammals Area (IMMA's).

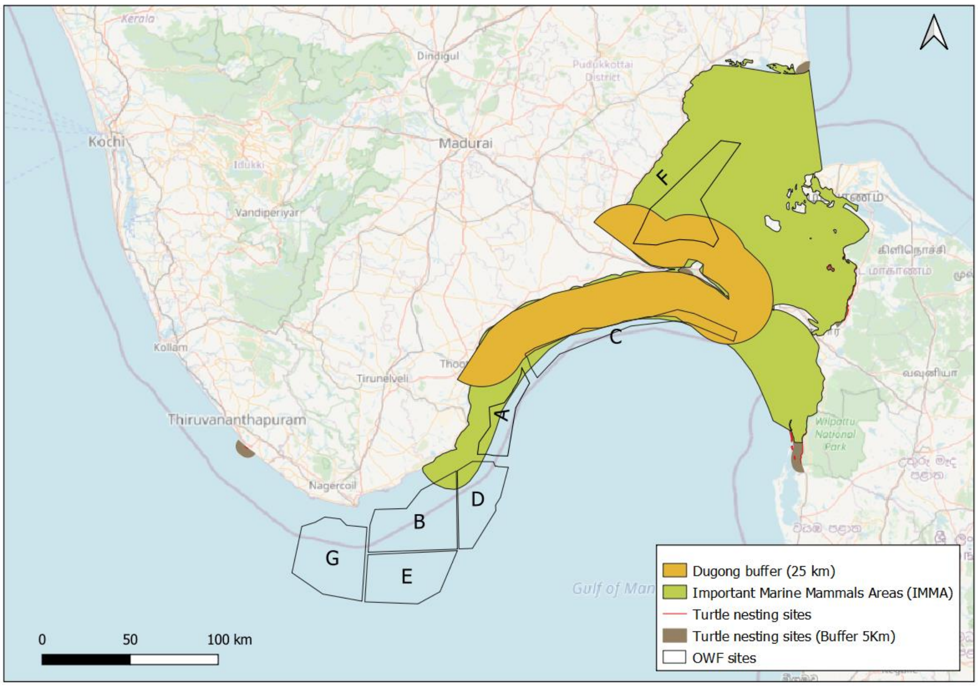


Figure 2.6 - Habitats and buffer zone for marine mammals and turtles around selected zones (COWI, 2021)

As observed from the figure above, parts of zone F and C are seen to be overlapping with the 25 km buffer area for Dugongs, which are to be considered as restriction zones. Also, some portions of zone D, A, C and F are seen to be falling within the IMMA.

It is clear that the OWF development within Zone F and potentially A and C would require further detailed environmental assessments to assess viability for offshore wind development within these zones.

2.2.3.3 Birds

As part of the designated LPAs and IRAs birds are also considered and specifically the identification of important marine bird areas including breeding colonies, foraging areas around breeding colonies, non-breeding concentrations, migratory routes and bottlenecks and feeding areas.

Several Important Bird Areas (IBAs) have been identified on land in proximity of the offshore windfarm sites, as provided below and shown in Figure 2.7.

The Gulf of Munnar Marine National Park, located off the coast near Rameshwaram is one of the first Marine Biosphere reserves of India and an important bird area which provides habitat for approximately 187 species of aquatic and terrestrial bird including waders and seabirds.

Peria Kanmai and Sakkarakottai Kanmai or Big Tank acts as a nesting site for large numbers of congregatory waterfowl and globally threatened species of Spot-billed Pelican (Pelecanus Philippensis). Significant numbers of heronry species have also been reported to be found.

Chitrangudi and Kanjirankulam Bird Sanctuaries located in Ramanathapuram, serves as an important breeding ground for around 100 species of birds, including the threatened species of Spot-billed Pelican (Pelecanus Philippensis).

Suchindram, Theroor and Vembanoor wetlands located in the southernmost tip of Kanyakunmari, the wetlands are an important habitat for around 250 species of birds, including 53 migratory species, twelve are endemic and four species threatened and are known to be important foraging grounds for threatened species.

Koonthangulam Bird Sanctuary is an important breeding area for several pelican species.

At Kalakad - Mundanthurai Tiger Reserve - located in the south western area of Tamil Nadu, approximately 273 species of birds are known to be present in and around the areas of the reserve including the globally threatened White-bellied (Shortwing Brachypteryx).

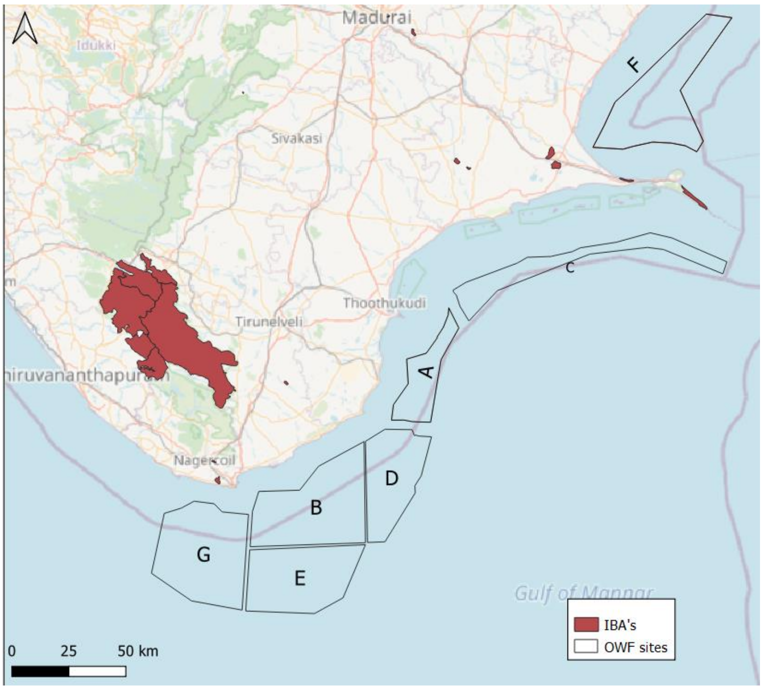


Figure 2.7 - Important Bird Areas (IBA's) near the OWF sites. (COWI, 2022)

However, additional information will be required to understand the migratory routes of birds, including 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, such as seagrass meadows and mangroves.

2.2.3.5 Natural Habitats

Several marine ecosystems are ecologically highly important for the country. These include e.g. 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 are cloud cover and noise, as well as areas, where land cover was misclassified. It is therefore suggested that a further assessment is conducted during the later phases of development through an Environmental Impact Assessment.

2.2.3.7 Sea Grass and Coral Reefs

Seagrass provides an important habitat for Dugongs and these areas have been included in the spatial GIS layer for marine mammals.

They are observed to be present in the areas near the Gulf of Mannar Marine National Park, near zone C (see Figure 2.8 below).

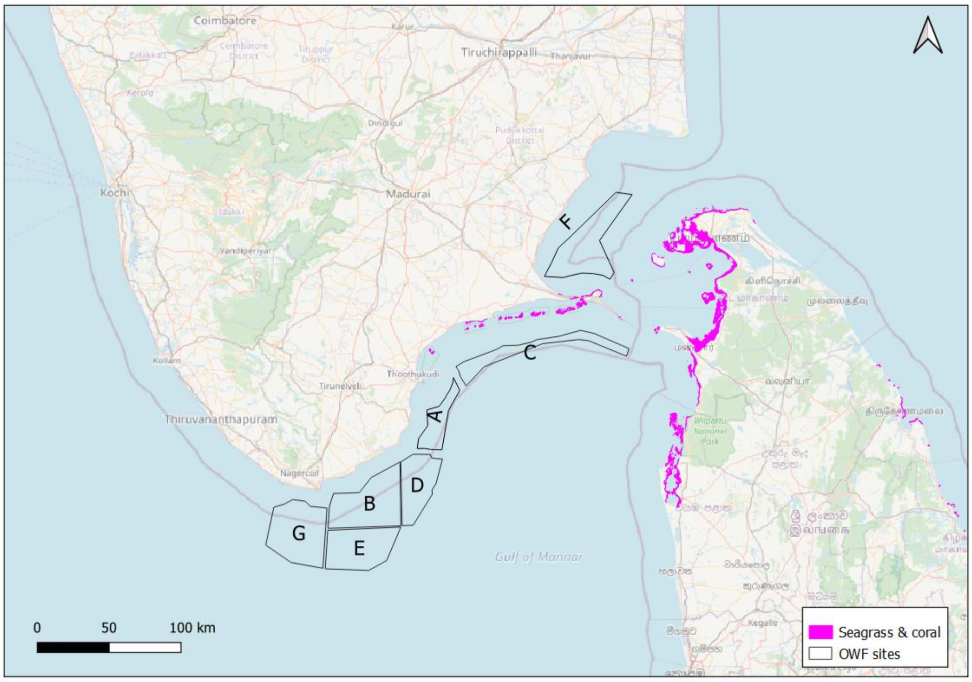


Figure 2.8 - Seagrass and warm water coral reefs in South India (COWI, 2021)

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 the further consideration of offshore wind farms and associated infrastructure (See Figure 2.9). In contrast, Restriction zones are the high-risk areas requiring further assessment during the ESIA, should they conflict with the OWF development planning for the selected zones in Tamil Nadu (See Figure 2.10).

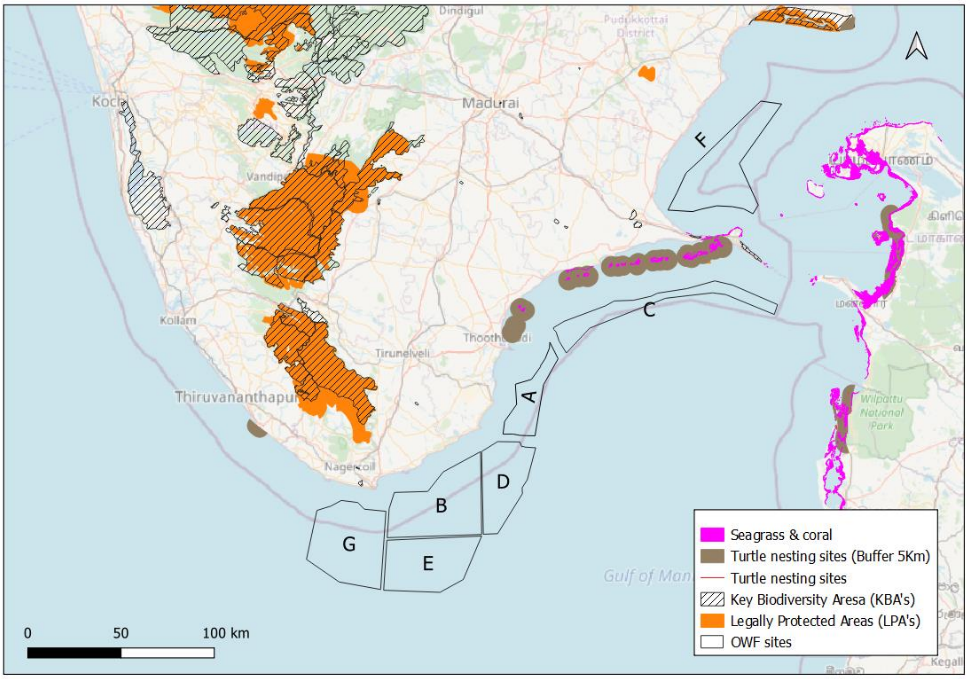


Figure 2.9 - Environmental constraint mapping -Exclusion zone around selected zones (COWI)

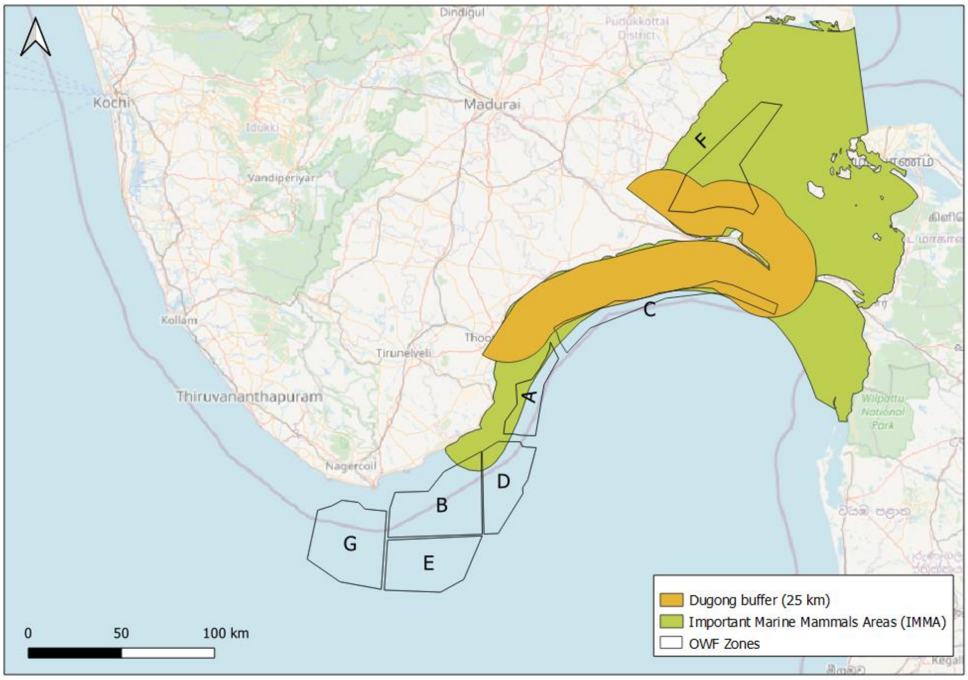


Figure 2.10 - Environmental constraint mapping -Restriction zone around selected zones (COWI, 2021)

The classification of the different environmental constraints and sensitivities is 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 Tamil Nadu

2.2.4 Social Considerations

Potential social constraints are also taken into consideration during the rough screening to reduce or avoid any conflict in the area under consideration.

Social constraints 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 and
- Cultural heritage, visual impact and tourism

2.2.4.1 Marine Traffic Considerations

Data obtained from World Bank and International Monetary Fund (IMF) is considered during rough screening to understand the marine traffic in Tamil Nadu and within the selected zones. The data is categorised into commercial, fishing, Oil and Gas, passenger and pleasure vessels.

Observations based on the data showed that the vast majority of the traffic consisted of commercial vessels mainly originating from the Tuticorin port and passing through the selected zones, which clearly indicated a significant potential conflict (see Figure 2.11).

Further evaluation of the data is considered necessary as part of the fine screening to be able to draw comprehensive conclusions. Therefore, further assessment of marine traffic data and analysis of the traffic intensity is provided in section 2.3.1 of this report.

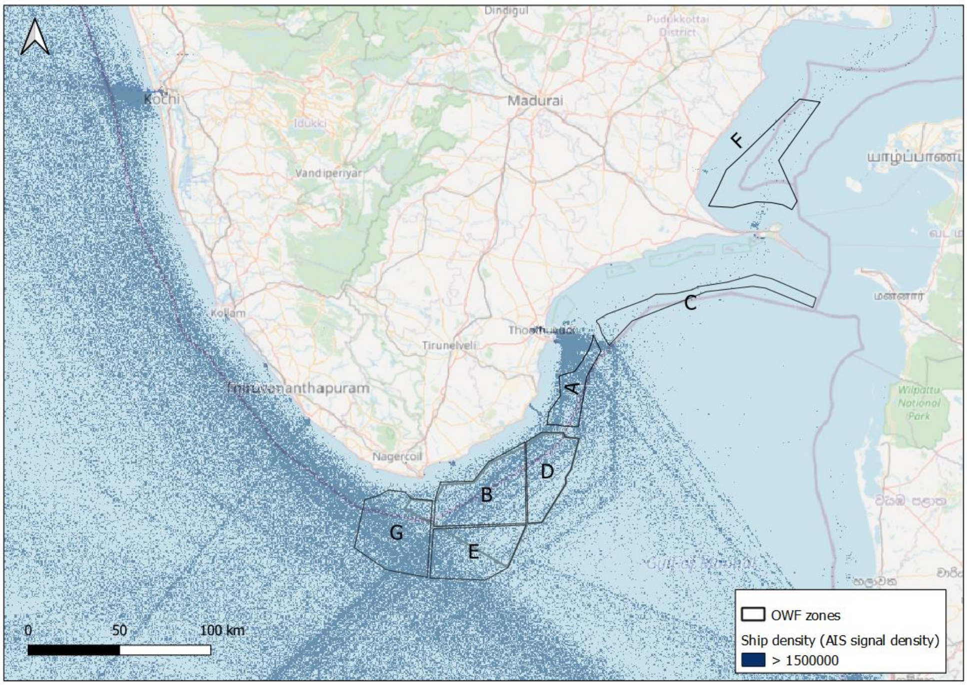


Figure 2.11 - Marine traffic in Tamil Nadu and around the selected zones (IMF, 2021)

2.2.4.2 Fisheries and Aquaculture

Aquaculture sites

The Palk Bay and Gulf of Mannar area are abundant in seaweeds and the Gulf of Mannar area, near zone C is well suited for seaweed farming. The Kanyakumari area lying close to zone B and G, in the southern tip of the Indian peninsula provides a large area for seaweed farming.

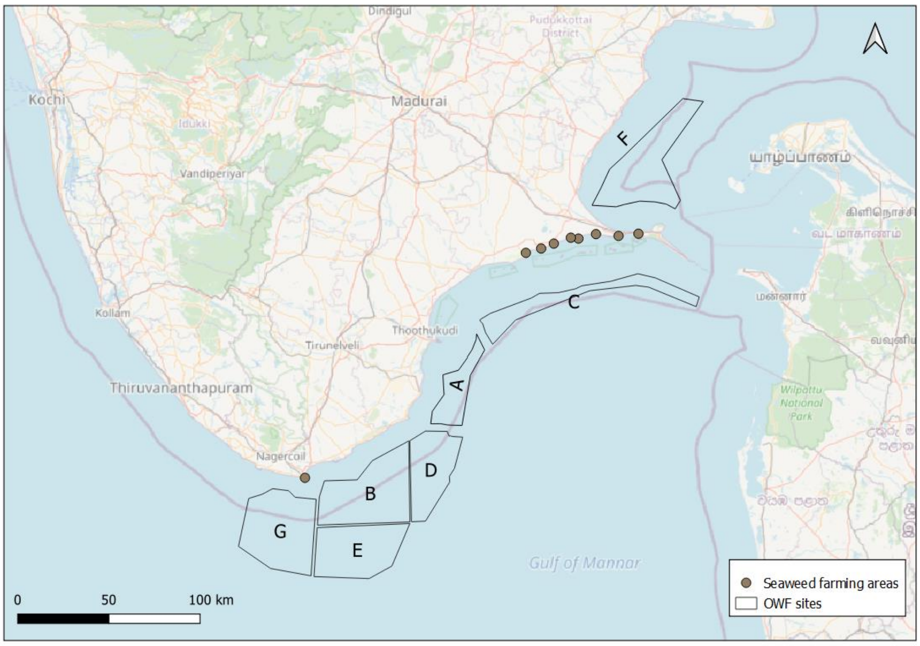


Figure 2.12 - Seaweed farming areas along the South Eastern coast of India (COWI, 2021) Fisheries

Fisheries

According to the "Fisheries At a Glance" document (Department of Fisheries and Fishermen Welfare, Government of Tamil Nadu) for Tamil Nadu prepared by The Department of Fisheries and Fishermen Welfare of Tamil Nadu for 2020-2021, Tamil Nadu is endowed with rich coastal biodiversity and abundant endemic fish species and thus it has one of the largest fisheries in India. It has 52 fish landing centres, 251 fish landing points, 9 major fishing harbours including the Chennai, Nagapattinam, Poompuhar, Mookaiyur, Thoothukudi, Chinnamuttom, Colachel, Muttom and Thengapattinam, 3 medium fishing harbours including Pazhayar, Cuddalore and Mallipattinam, 608 marine fishing villages and a projected fisher folk population of 10.48 lakh persons. The marine fish production over in 2020-2021 has been around 1.1 million tonnes, which accounts for approximately more than 12.5 per cent of annual total marine fish production in India. According to the policy note prepared in 2022 by the same department, there are 5,924 mechanized and 43,982 traditional fishing crafts, which are actively engaged in fishing. The total coastline and important zones for fishing activities can be seen in Figure 2.13.

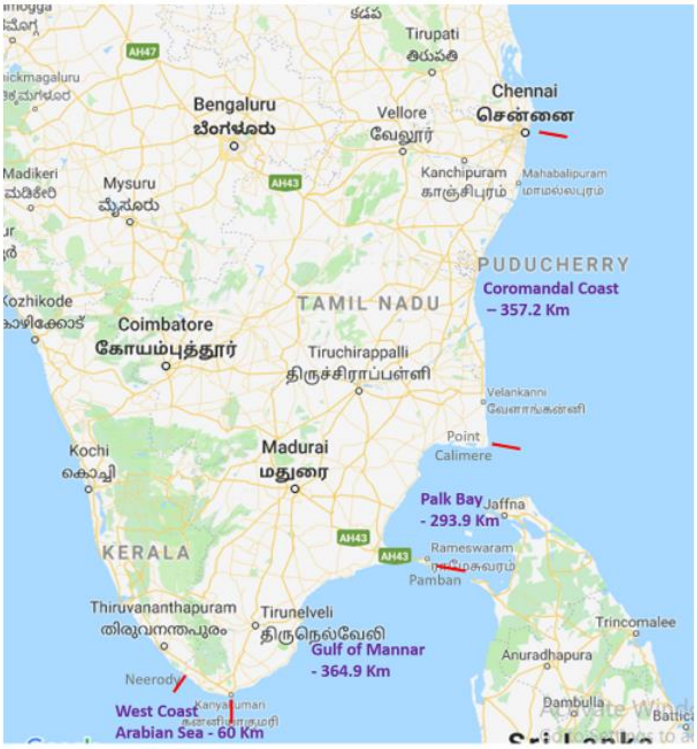


Figure 2.13 - Coastal Length of Tamil Nadu used for fisheries

The Gulf of Mannar is known to be a productive ecosystem and therefore fishing is one of the key economic activities for the surrounding population. Two (2) fishing harbours (Thoothukudi and Chinnamuttom) and ten (10) fish landing centres have been established by Department of Fisheries, in the areas around the selected zones and are illustrated in Figure 2.14.

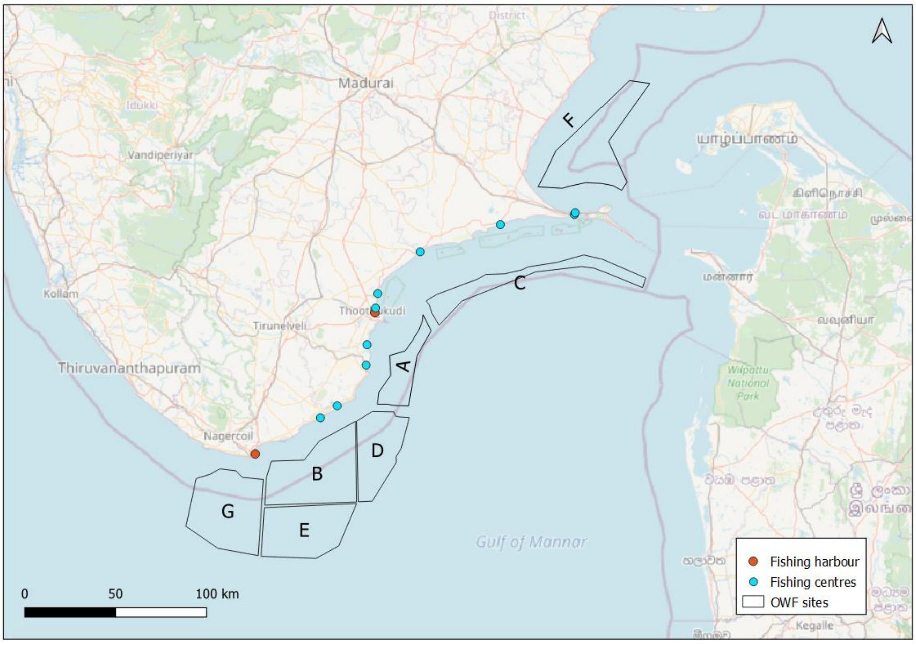


Figure 2.14 - Major fishing harbours and fish landing centres around selected zones (COWI, 2021)

2.2.4.3 Oil and Gas Platforms and Exploration Areas

With regards to existing oil and gas platforms and pipelines, spatial data obtained from the Global Oil and Gas features database has been reviewed, and this shows no oil and gas platforms and pipelines within or in the proximity of the selected zones, except two oil fields which are observed to be located around the northeast and southwest corners of zone F. (see Figure 2.15).

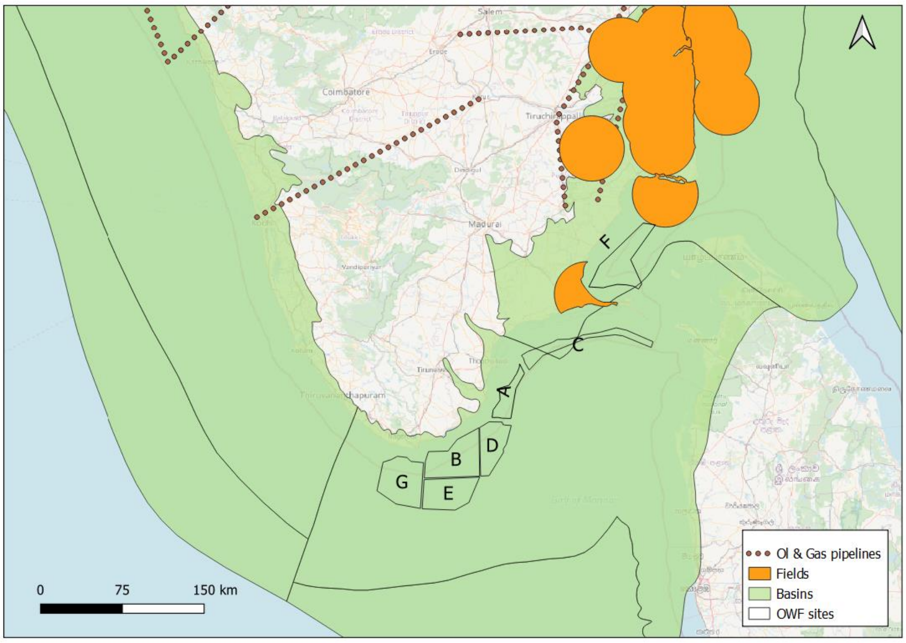


Figure 2.15 - Oil and gas pipelines, oil fields and basins in South India (around selected zones) (EDX, 2021)

Additional maps of Producing Fields under PSC Regime (See Figure 2.16) have also been considered relevant, which further confirms no oil and gas platforms and pipelines within or in the proximity of the selected zones in Tamil Nadu.

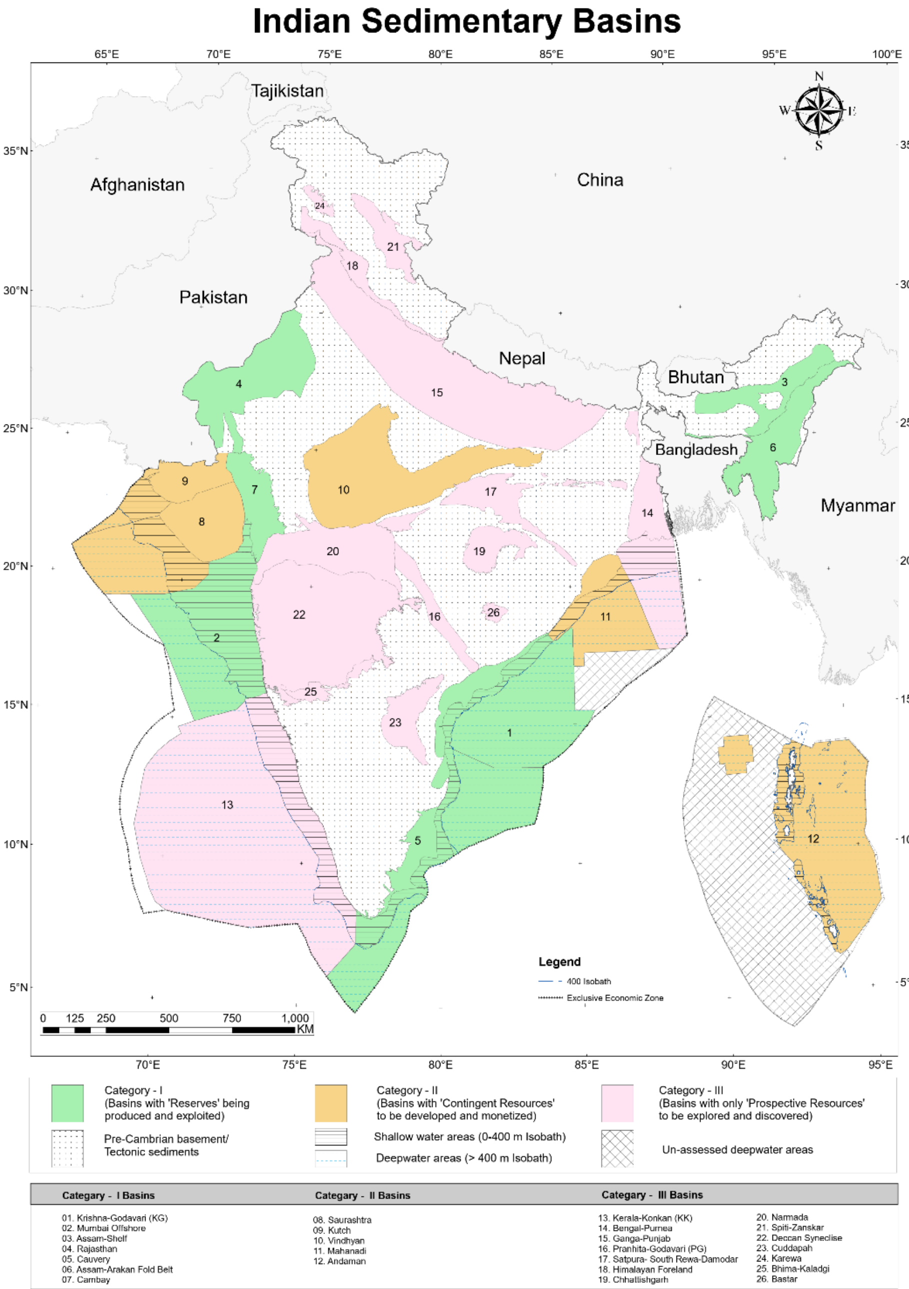


Figure 2.16 - Indian sedimentary basins (DGH, Indian Sedimentray Basins, 2022)

The general area in and around Tamil Nadu lies in the Cauvery Basin which is one of seven basins that is a sink to 85% of all "unrisked conventional hydrocarbon" in India (see Figure 2.17). However, most of the offshore areas and coastal areas in the Cauvery Basin are considered to be a "relinquished area". Henceforth, in the areas near selected zones, production plans have been withdrawn, and oil and gas exploration is not presently considered. However, 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).

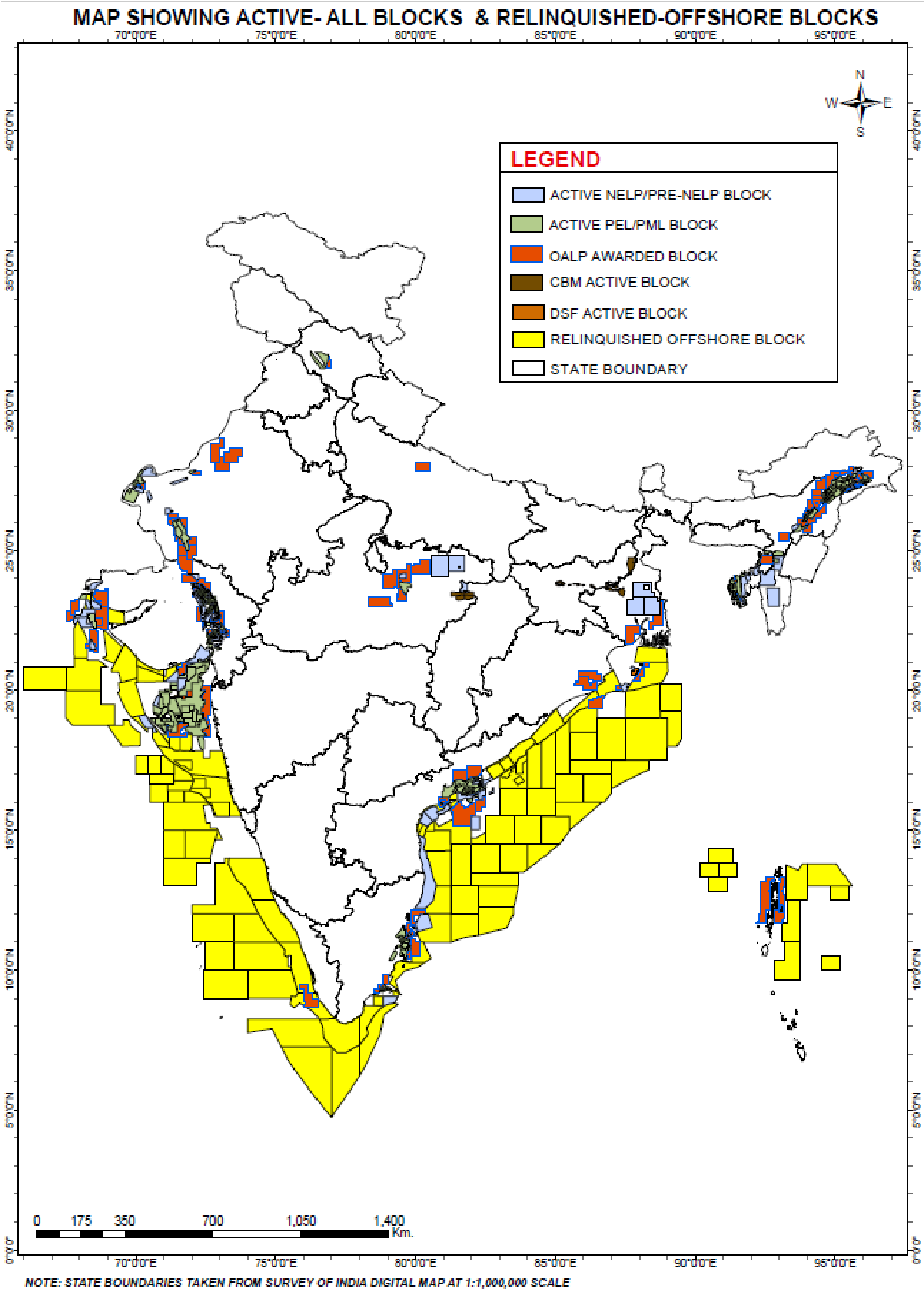


Figure 2.17 - Active-all blocks and relinquished-offshore blocks (DGH, Maps of active (all) and relinquished offshore blocks, 2022)

2.2.4.4 Submarine communication and power cables

Submarine cables are concentrated both in the Indian Ocean and Arabian Sea. Figure 2.18 illustrates the submarine cables in South India and their landing points. It is observed that the Bharat Lanka Cable System (connected to Sri Lanka) with landing point at Tuticorin (Tamil Nadu) is intersecting zone A and D, which will need to be considered.

Therefore, it is advisable to consult with the Ministry of Ports, Shipping and Waterways to identify critically important constraints and for subsequent planning purposes.

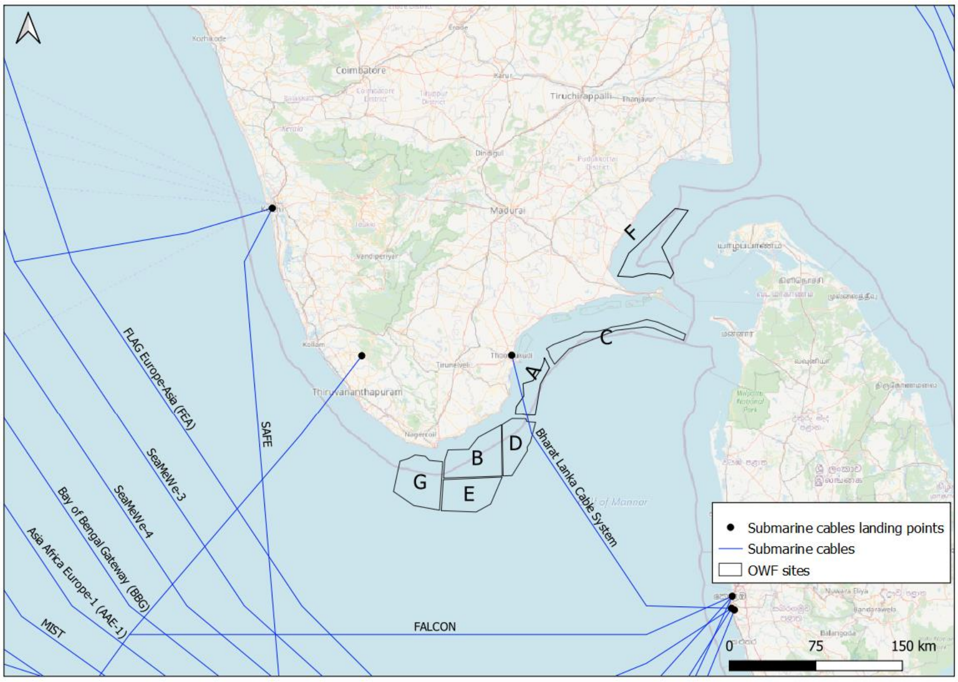


Figure 2.18 - Submarine cables in South India (TeleGeography, 2021)

2.2.4.5 Military defence areas

It is understood that the Ministry of Defence (MoD) has given in-principle clearance for the zones A, B, C, D, E, F and G in Tamil Nadu. Therefore, conflict with defence sites is not considered as a potential constraint during the Maritime Spatial Planning for the most attractive zones for the development of offshore wind.

2.2.4.6 Cultural heritage

The following five (5) sites protected by the Archeologically Survey of India (ASI), identified (see Figure 2.19) in the rough screening, are located in proximity to the selected zones:

- Swami Vivekananda Rock memorial; and
- Vattakottai Fort
- Parthasarathy and Krishna temple
- Chitharal Jain monuments; and
- Prehistoric and historic sites

Presently, no submerged archaeological sites (such as sunken village) have been identified around the southern coast of Tamil Nadu. It is highly unlikely that such underwater sites would be present within the selected zones, which could forbid the consideration of these areas for offshore wind development. However, it is recommended to undertake consultations with ASI in order to confirm this.

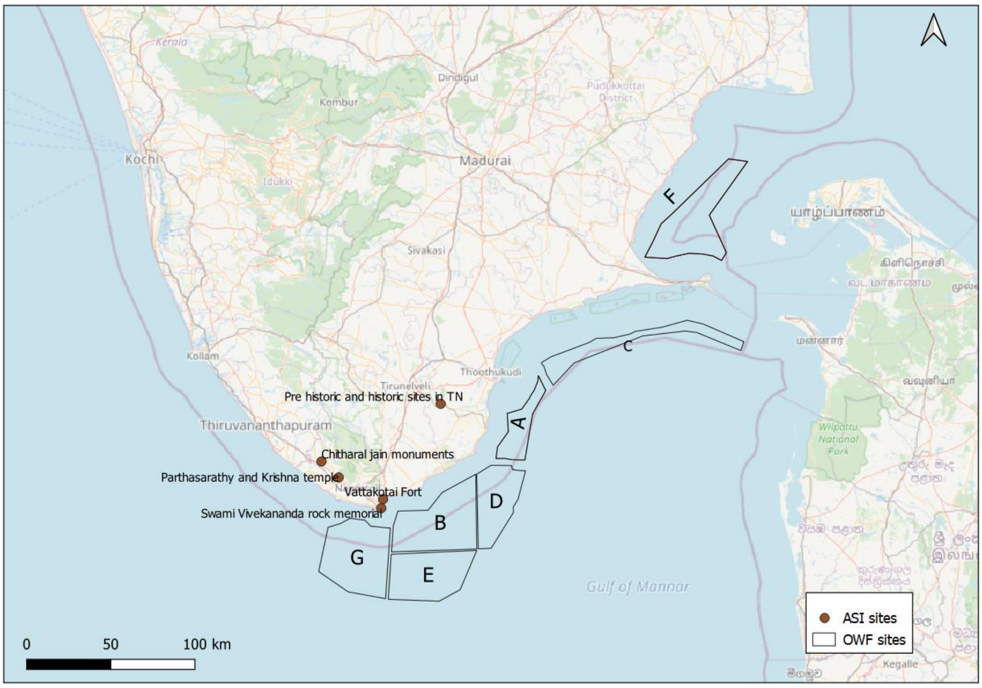


Figure 2.19 - Cultural heritage around selected zones (COWI, 2021)

2.2.4.7 Important areas for tourism/visual impact

Most of the tourist sites identified around the selected zones are of religious / cultural significance as depicted in Figure 2.20. Churches and temples play a significant role in the socio-cultural fabric of the community in southern Tamil Nadu and are one of the important stakeholders considered for development projects in the area.

Rameshwaram Island, situated at the very tip of the Indian peninsula in the Ramanathapuram district is of great significance to Indian history and attracts a large number of tourists and pilgrims every year. Also known as the Pamban Island, it is connected with the Indian mainland by Pamban Bridge on Pamban Channel in Gulf of Mannar.

The place is surrounded by several temples built in Dravidian style architecture including the Ramanathaswamy temple, Dhanushkodi temple, Tirtham and Panch - Mukhi Hanuman Temple.

The bridge connecting India to Sri Lanka, which is named as 'Rama Setu', also known as Adam's Bridge is of religious as well as ecological importance to the country.

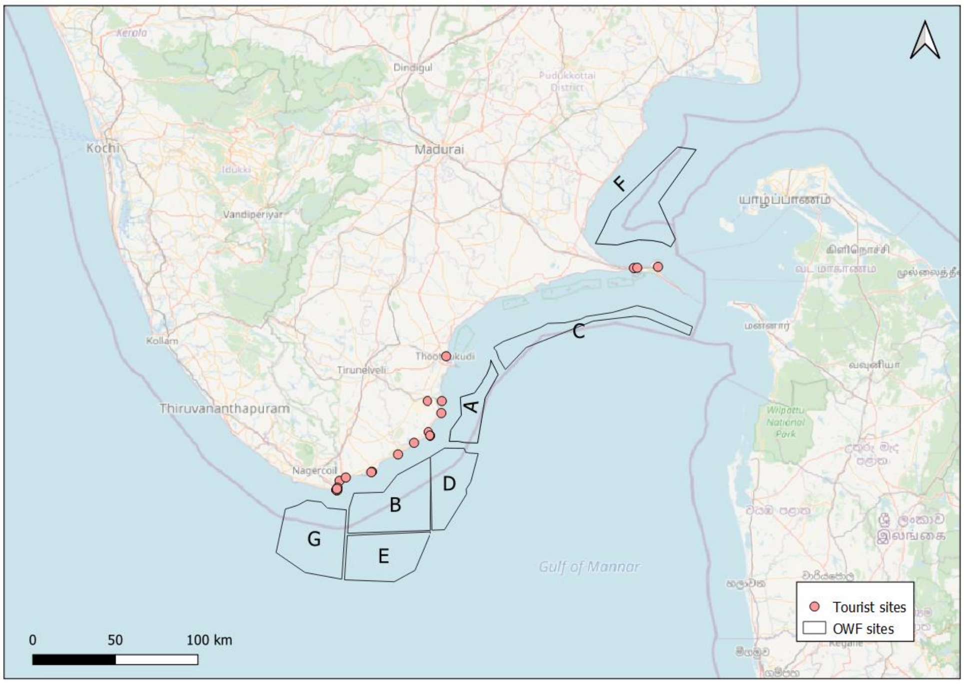


Figure 2.20 - Tourist sites around selected zones (COWI, 2021)

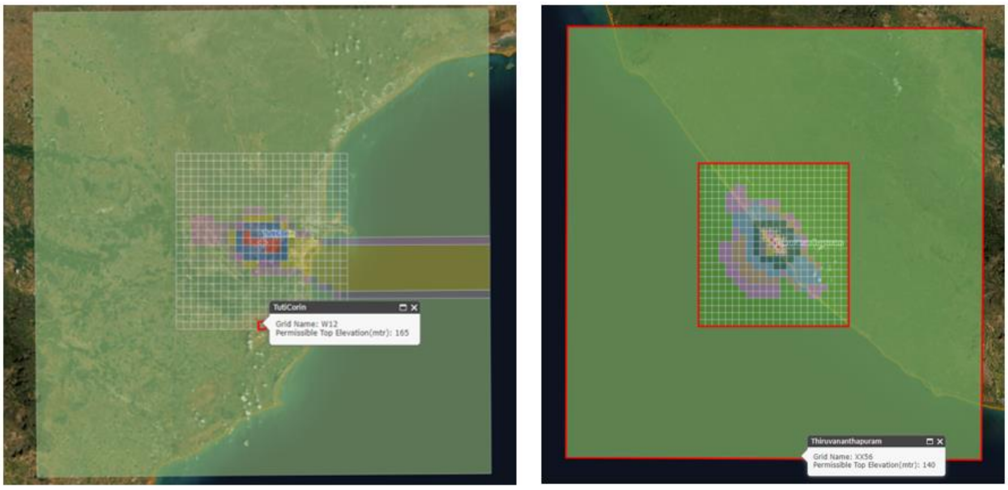
However, in terms of visual impacts it is still unknown as to how the offshore wind farms will be viewed by the local community (as there is no precedence). This evaluation needs a significant amount of stakeholder consultations, especially with the local community, which is considered to be outside the remit of this study. However, it should be noted that many onshore wind farms are currently present in the coastal areas around the selected zones and there is no documented evidence of local communities having previously objected to their presence, on the account of visual impacts.

2.2.4.8 Aviation, radar and telecommunication

Four (4) Radar/Air Traffic Control towers were identified in proximity to the selected zones, as given below:

- Helipad near Gandhi Ashram
- Indian Naval station
- Tuticorin airport
- Trivandrum airport

It is determined that the civilian airports will not pose any challenge / restrictions to the development of OWFs at the selected zones. The restriction zones around Tuticorin and Trivandrum airport are illustrated in Figure 2.21.



Turicorin Airport Trivandum Airport

Figure 2.21 - Airport Authority of India- Restricted zone around Tuticorin and Trivandrum Airport (AAI, 2021)

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 can further be 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, this could act as the constraint for OWF development within the shortlisted area.

2.2.4.10 Construction harbours and operational ports

A total of three (3) major and 22 minor ports have been identified in the Tamil Nadu region. Out of the 22, ports potentially suitable for construction activities were identified, namely:

- Kattapalli Port
- Chennai Port
- Tuticorin Port

The port of Tuticorin is approximately 50 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 2.3.4 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

National Grid in India has an installed capacity of approx. 407 GW and Renewable Energy (RE) power plants constitute approximately 28 % (approx. 118 GW) of this power capacity. India’s grid is connected as a wide area synchronous grid normally running at 50 Hz and is the largest operational synchronous grid in the world (as of June 2020).

Given the ambitious target of achieving 175 GW of RE power by the year 2022, the expansion of grid infrastructure continues at a rapid pace.

In the 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 Tamil Nadu Transmission Company (TansTransco) is responsible for erection and maintaining the grid system within Tamil Nadu.

Under "One Nation One Grid" policy, the Indian Power system for planning and operational purposes is divided into five regional grids. The integration of regional grids which began with asynchronous HVDC back-to-back inter-regional links facilitating limited exchange of regulated power was subsequently graduated to high-capacity synchronous links between the regions.

The transmission network expansion is aimed at evolving a national power grid to facilitate free flow of power across regional boundaries, raising the transmission voltage from 230 kV to 400 kV level. In order to evacuate bulk power from one region to another region, there are further plans for enhancing the transmission capability to 765 kV level.

Power Grid Corporation of India (PGCIL) is working towards the enhancement of the country's grid by adding more substations of 400kV, 765kV HVDC up to 1200kV HVDC. In Tamil Nadu, PGCIL has ten (10) 400 kV substations. 4 substations are of 765 kV of which some are currently charged at 400 kV only.

Several substations of different kV ratings are found in the coastal regions in the vicinity of the proposed wind farms around the zones, which are illustrated in Figure 2.22 below.

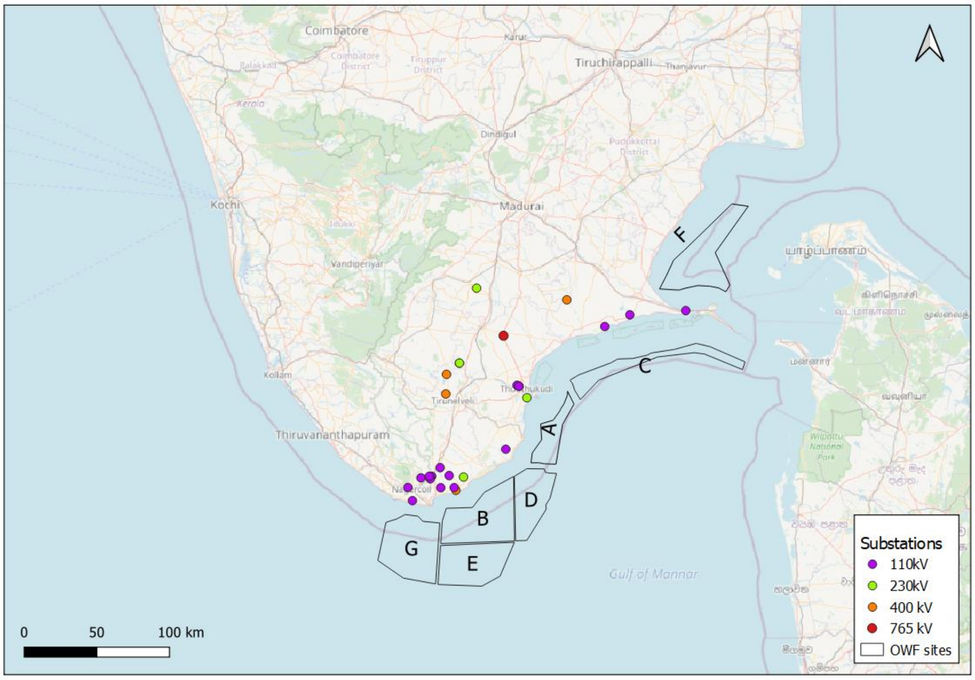


Figure 2.22 - Electrical onshore substations in vicinity of selected zones (COWI, 2021)

The following three (3) onshore substations appear to be promising for potential connection to the wind farms in the vicinity of zone B (see Figure 2.23):

- Sanganeri Substation (230 KV)
- Udayathur Substation (230 KV)
- Koodankulam Substation (400 KV)

All of the above onshore substations are located within 20 km from the boundary of the zone B. While 230 KV substations are acceptable for early phase / demonstration project (say 500 - 700 MW), connections to 400 KV substations would be required for large scale development of offshore wind zones.

The closest 400 KV substation is the Koodankulam substation, which is currently connected to Koodankulam Nuclear Power Plant and is expected to have significant balance capacities for upgrade given the expansion plans of this Nuclear Power complex.

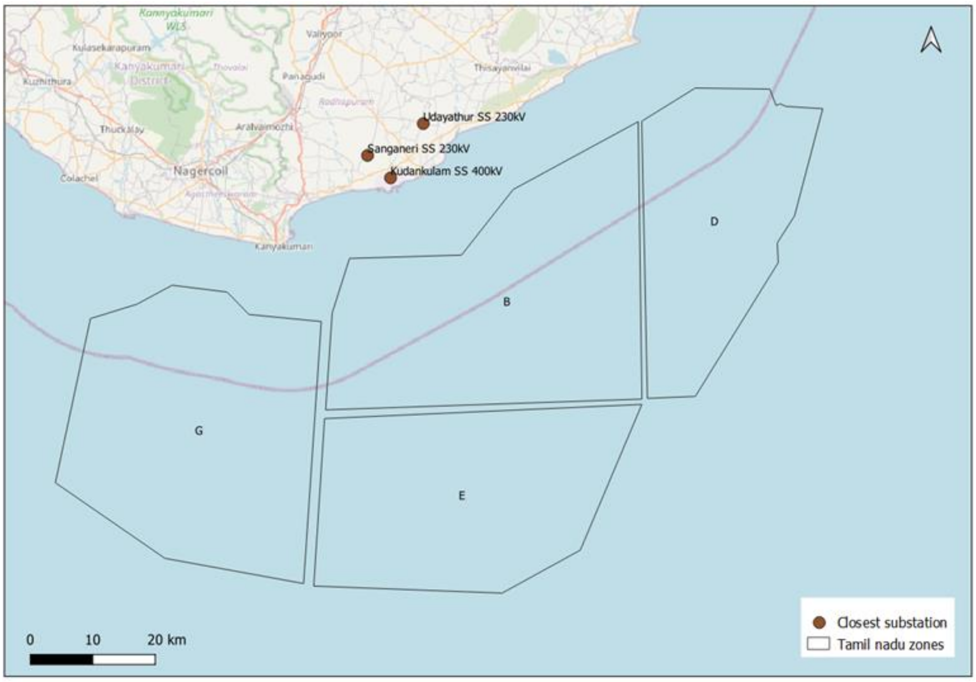


Figure 2.23 - Substations near the zone B (COWI, 2021)

2.2.6 Summary and conclusion

The rough screening provided a high-level overview of the potential constraints for offshore wind development in the selected zones of Tamil Nadu, based on publicly available data and information. Further consultation is however required with the relevant stakeholders to identify any potential constraint(s), especially with regards to fishing activities, marine traffic, tourism, oil and gas exploration activities, military and defence activities within and near the selected zones to be able to reach a comprehensive conclusion for development of offshore windfarms in the area. The outcome of the rough screening and the key findings are summarised below.

- Wind Resource: the prevailing wind conditions at most zones are considered as favourable for development of OWF at the site with average wind speed > 7 m/s at 150m height, except for zone F where observed wind speed is <7m/s at 150m height.

- Bathymetry: the water depth ranges from 10m to 65 m and as such is considered to be suitable for installation of fixed bottom foundation wind turbines.

- The key sensitive environmental habitats with high biodiversity, around the zones have been mapped based on publicly available information. Most of the areas within the OWF zones are at significant distance from the exclusion zones considered, however a small portion of zone A, B, C and D overlaps with identified environmental restriction areas. With regards to the zone F there is a complete overlap with the identified environmental restriction areas.

- Fisheries and aquaculture: The OWF zones are located in Gulf of Munnar, an area considered to be highly productive for fishing. Further studies, including stakeholder consultations are required to fully understand the potential constraints and focus required to ensure co-existence between fisheries and offshore wind development.

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

- Cyclone: According to the State of Environment Report (SoER) prepared by the Department of Environment of the Government of Tamil Nadu in 2017, northern Tamil Nadu experienced, on an average, 6 cyclones in each decade over the period 1891-2007, whereas southern Tamil Nadu experienced, on an average, 1 cyclone over the same period. A higher percentage of cyclones occurred during the north-east monsoon season (i.e., October-December).

- Oil & Gas production activities: There are no known O&G production / exploration activities currently being undertaken at OWF zones, however further liaison with stakeholders is critical to confirm this assessment and understand constraints (if any).

- Submarine and Power Cables: a submarine cable connecting India and Sri Lanka passes through north-eastern and south-western corner of Zone D and A respectively.

- Cultural Heritage and tourist areas: Cultural heritage and tourist areas in vicinity of the Zones are mapped, at present they are not considered restrictive for OFW development at the considered zones. However this will need to be further considered during the development for potential visual impacts as well as constraints that these sites may present for enabling infrastructure (such as substations).

- Defence areas: It is understood that offshore wind development in the zones A, B, C, D, E, F and G have been cleared by MoD.

- 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 understanding the constraints and develop potential strategies for mitigation.

- Raw material and dredging areas: Currently no information is available that suggest the zones are used for extraction of raw material / dredging areas. However, this needs to be confirmed in consultation with the relevant Indian stakeholders.

- Ports and Harbours: Tuticorin Port, is located approximately 50 -150 km from the areas within the considered zones. Therefore, it could potentially support the offshore wind farm construction and installation activities for OWFs in these zones. A more specific port study, which has been initiated by the Danish Energy Agency together with MNRE and NIWE, will clarify this.

- Grid and electrical infrastructure: Various substations with rated capacities of 230 and 400 kV are found in the vicinity of zones, which could aid power evacuation to the regional / national grid, but this would need to be further analysed.

- Marine Traffic: It appears that an international marine traffic route (towards Sri Lanka) passes through Zone G and Zone E. Further significant marine traffic in a Northwest and Southeast direction, also appears to pass through the OWF zones. Therefore, commercial shipping traffic appears to be at direct conflict with the planned OWF development and requires a further detailed assessment.

In conclusion, offshore wind development zones in Tamil Nadu (Zone B, D, E and G) offers some of the best available sites for offshore wind development projects within the country, with relatively high wind speeds, reasonable depth to the seabed and limited conflicts with environmental and social receptors. It is expected that the OWFs within these zones to be prioritised as compared to zones A, C and F.

Specifically Zone F, which experiences low wind speeds (<7.0 m/s) and shallow water depths (<10.0m) is not conducive to a large-scale offshore farm development. The shallow depth could potentially restrict the ability of large marine construction vessels to access the site, without significant dredging. As zone F is located within IMMA, a detailed assessment, based on various environmental surveys, is required to evaluate the viability of Zone F for offshore wind farm development.

Based on the rough screening undertaken, marine / shipping traffic is assessed to be the most significant competing user to the offshore wind development, within the best available sites for offshore wind development and is therefore considered further during the fine screening.

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

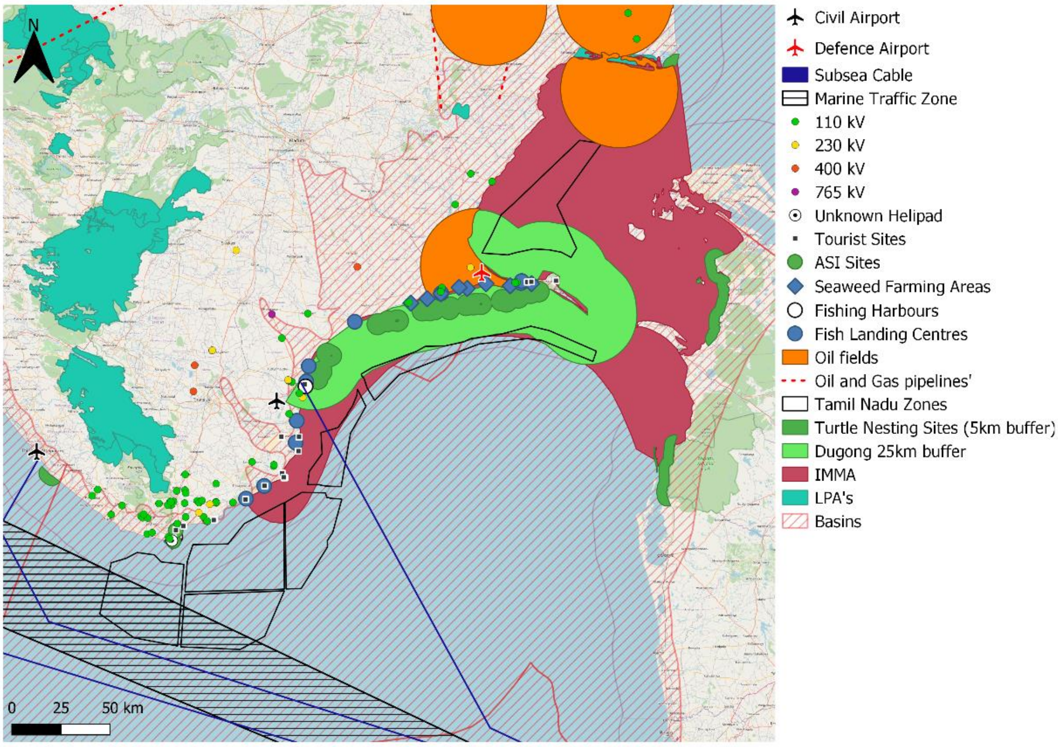


Figure 2.24 - Rough screening of coastal area in Tamil Nadu

Figure 2.25 represents a classification of the offshore area according to the criteria assessed during rough screening. The offshore wind zones are plotted with a black line based on the pre-feasibility study of FOWIND project. A traffic light scheme is used to classify different sections of the whole coastal area with the representation of different colours explained in the legend of the figure. Areas specified as "No-Go" with red colour 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 in section 2.2.3.8 . Areas specified as "Restriction / Negotiable" with yellow colour are IMMAs and areas reserved for Dugong marine mammals with 25 km buffer around them especially getting close to the site border of A, B, C and D. These are mentioned as restriction zones in section 2.2.3.8 . In addition to exclusion and restriction zones, areas specified as "Restriction / Negotiable" with orange colour are reserved for setting the boundary for best conditions for fixed-bottom foundation turbines taking bathymetry and wind speed into consideration. Finally, the maritime traffic zone is represented with a shaded area in order to specifically emphasize borders overlapping with offshore wind zones. Further consideration on the zones represented with yellow and green colours will be taken in the fine screening process in the next section.

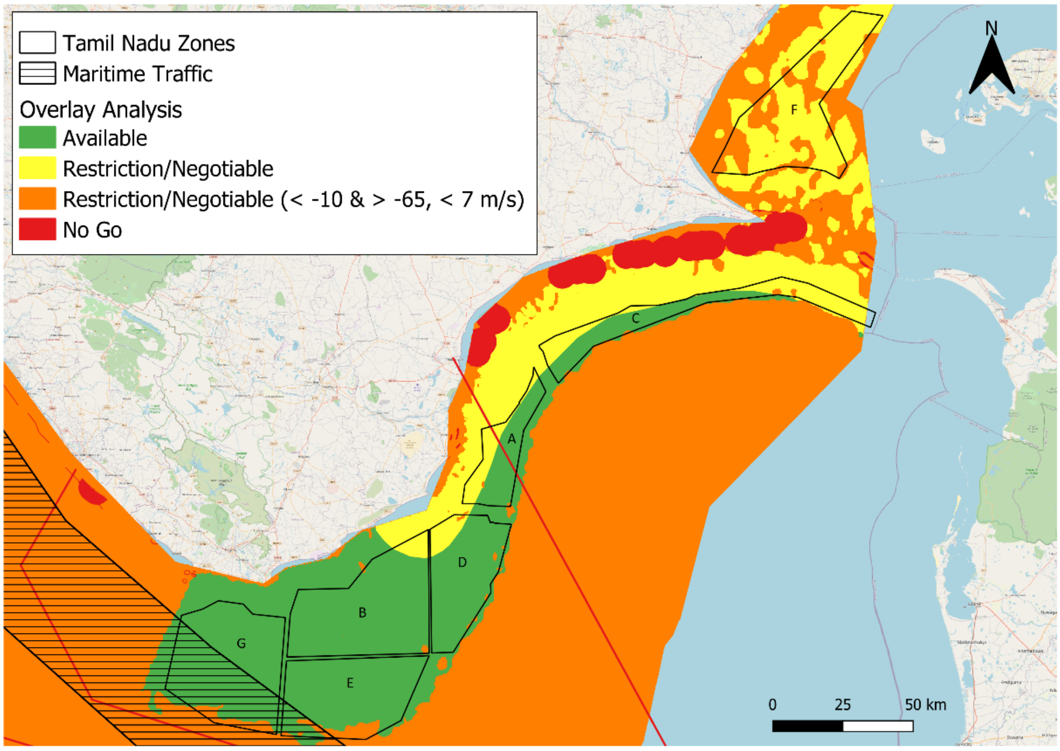


Figure 2.25 - Traffic light classification of offshore wind zones resulted from rough screening

2.3 Fine Screening

2.3.1 Marine Traffic Considerations

Marine traffic considerations have been taken into account in the "Technical Note" on Marine Traffic Assessment in Tamil Nadu, where a detailed analysis of marine traffic in the region has been performed. The conclusions and findings from that report is included in this section but please refer to that Technical Note for more details.

In order to obtain a comprehensive picture of the marine traffic in and around the OWF zones, AIS data has been procured from marinetraffic.com and has been analysed for the entire calendar year 2019. AIS (automatic identification system) is a GPS-based digital service that is mandatory for all ships above 300 gross tonnages as well as tankers and passenger ships of even smaller sizes. Thus, all ships relevant for this study are covered by AIS. 2019 has been used as reference year, as this is the most recent contingent calendar year that has not been subject to the significant temporary drops and rises in traffic volumes caused by the COVID-19 pandemic.

Traffic intensity plots are prepared based on AIS data to visualize the traffic pattern in the area of interest. Figure 2.26 provides intensity plot considering all types of vessels.

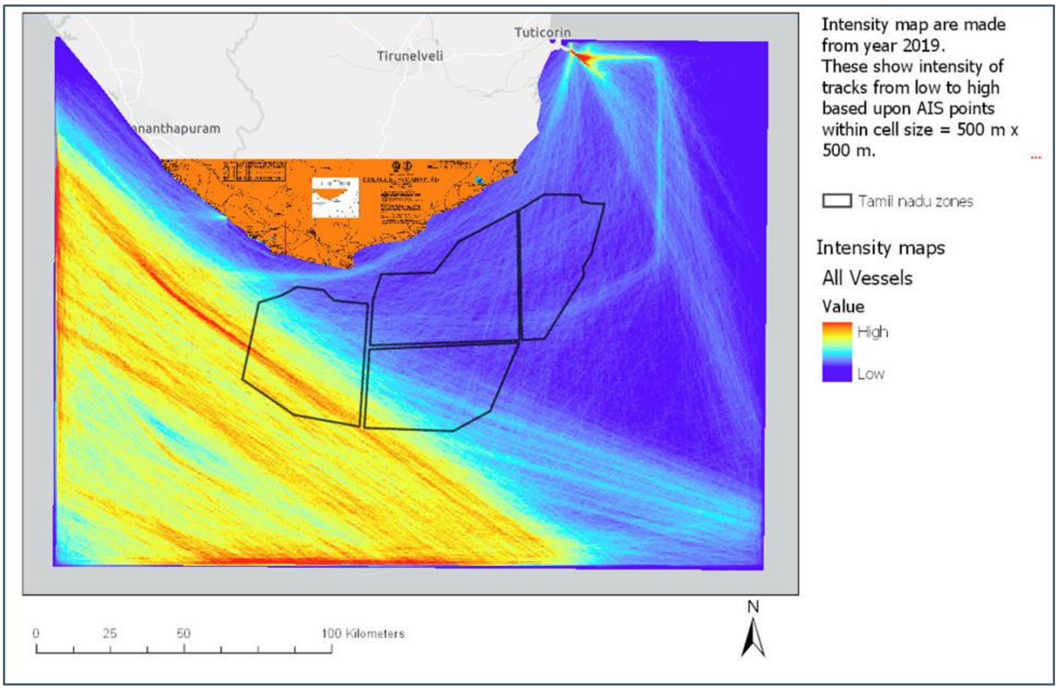


Figure 2.26 - Traffic intensity map around OWF zones – all vessels

The observations confirmed that:

- The offshore wind farm construction within Zone G and Zone E (at least partially) will be in potential direct conflict with an international traffic route (ships travelling to Colombo and those circumventing Sri Lanka), having significant vessel density. This clearly requires a closer implementation of strategies to de-conflict this competing usage. A well-considered and designed, Traffic Separation Scheme (TSS) could be one of the alternatives to achieve the objective of mutual co-existence for both the competitive users (offshore wind development and marine traffic) of this important sea space.
- For the rest of the OFW areas, the traffic seems to be modest.
- The OWF areas have reasonably high fishing vessel traffic, which reconfirmed the observations during rough screening that these areas support high level of fishing activities.
- No clear pattern of commercial shipping traffic route between Tuticorin Port and Male (towards southwest, perpendicular to international shipping route), passing through OWF zone was observed.

Traffic counts and crossline analysis has been performed based on the traffic intensity map in order to be able to identify shipping traffic volume passing through the specified crosslines. These crosslines can be seen in Figure 2.27.

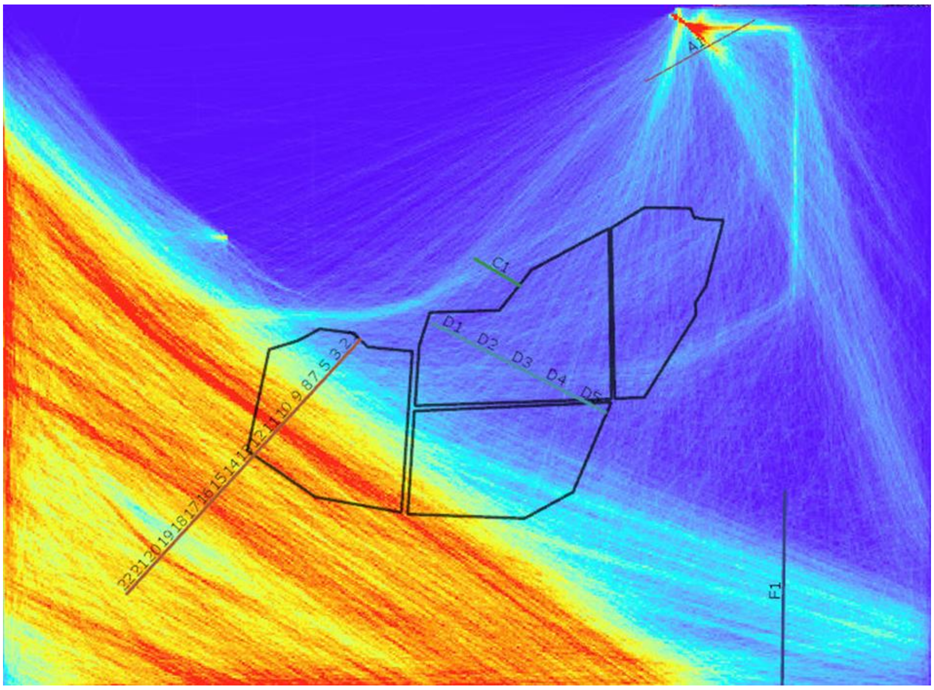


Figure 2.27 - Location of crosslines

Data collected for each crossline can be seen also in the below representation in bar chart form:

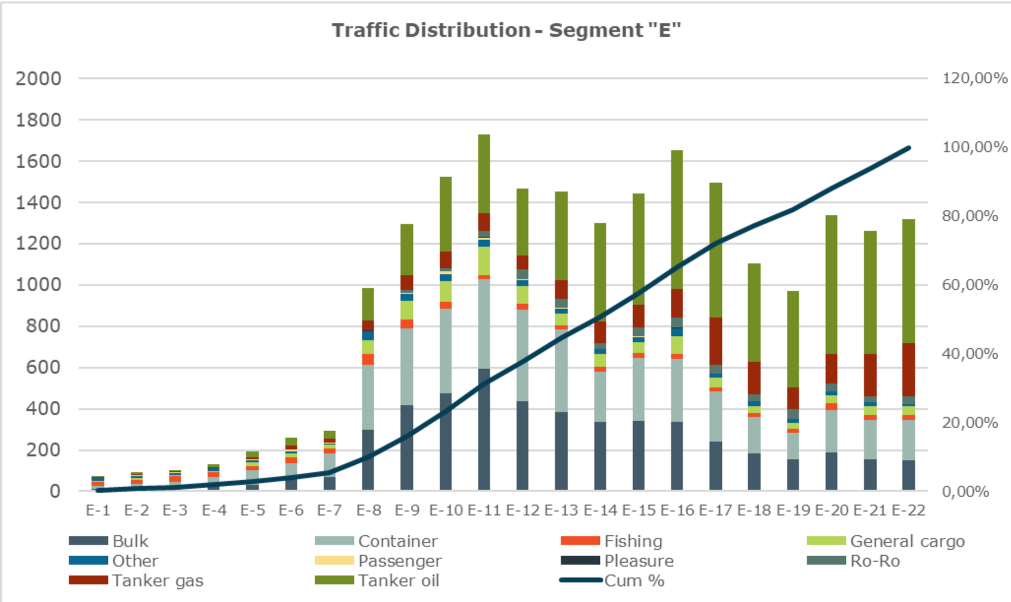


Table 2.2 - Number of vessels passing through each crossline

It can be seen from the above figure that large international marine traffic passing through the Zone G and Zone E is in potential conflict with offshore wind farm development in these zones. Most of the traffic is caused by commercial vessels such as bulk carriers and container ships as well as oil tankers.

2.3.1.1 Considerations on safe distance to outer OWF boundary

Approaches of different countries have been analysed to determine the approach in setting the safe distance to outer offshore wind farm boundary. The Danish experience shows that ships will naturally keep an average distance of 2,400-2,500 m to the nearest turbine on a route with a moderate traffic volume. A standard deviation of 600 m implies that 90 % of the traffic would be sailing within a band of 2,000 m width, i.e. at a distance of 1,400 (closest edge) to 3,400m (furthest edge) from the nearest turbine. The 1,400 m corresponds well to a mariner's ship domain (buffer zone around the ship kept by mariners) described in the UK guidance.

However, if traffic is more intense – as is the case at the south-western boundary of the Tamil Nadu OFW area – it will not be possible to sail safely at such a close distance (1,400 m) to the OWF. This is presumably also the reason why the UK guidance indicates the risk as being "high" at such a distance.

If the OWF is built as planned in its full extent towards the southwest and if no other measures are taken (such as TSS), some of the ships will likely concentrate at such a close distance, creating a dense and potentially unsafe traffic situation.

According to the UK guidance, a safe distance would be somewhere between 2 nautical miles (3.75 km, low risk) and 5 nautical miles (9.25 km, very low risk) from the closest edge of the route.

2.3.1.2 Considerations on corridor width inside OWF area

The number of ships passing the OWF area in a north-south direction is moderate (1,650 ships per year). Thus, the minimum route width used in the German North Sea, i.e. 6 km plus 0.5 km safety zone on both sides, is likely to be sufficient. This distance will allow ships to pass each other at a distance of 2 km whilst keeping a distance of 2.5 km to the nearest turbine.

2.3.1.3 Traffic Separation Scheme (TSS)

Ship routing systems are established in consultation with the International Maritime Organisation (IMO) in congested shipping areas of the world for safety reasons. The routing systems consist of Traffic Separation Schemes (TSS) which include two-way routes, recommended tracks, deep water routes, precautionary areas (where ships must navigate with particular caution), and areas to be avoided for reasons of exceptional danger.

At present, any TSS being implemented in and around the southern coast of Tamil Nadu is not known. Accordingly, it is recommended that the relevant government agencies adopt a prudent traffic separation scheme to reduce the potential conflict and navigational risk posed by offshore windfarm development to the marine traffic.

Based on the marine traffic data, significant international ship traffic is observed in the northwest-southeast direction, passing through the Zone G and Zone E of Tamil Nadu. A significant portion of these zones lies within the extended economic zone and outside the territorial water of India. International Navigation has received extensive protection under United Nation Laws of the Sea (UNCLOS).

Accordingly, it is suggested that a TSS could be established in this area, respecting current routes of existing international marine traffic and their freedom of navigation.

The TSS needs to be designed to accommodate an overall traffic of approx. 22,000 ships per year, corresponding to 11,000 ships per directional lane. According to the Dutch guidance, this would require a width of 2,400 m for each of the two traffic lanes. The traffic at question is spread over at least 50 km in width. Thus, traffic lanes significantly wider than 2,400 m are easily feasible and likely to be the solution of choice.

Traffic passing the area in the north-eastern and south-western direction is comparatively moderate:

- Approx. 500 vessels per year are sailing close to the coast northwest of the OFW area. This corresponds to 1½ vessels per day.
- Approx. 1,650 vessels per year are sailing through the OWF area. This corresponds to 5 vessels per day spread out over a width of 50 km.

The main purpose of a TSS is avoiding crowded and unclear situations potentially leading up to collisions. With the above traffic numbers, this precondition is not met, although collisions of course can occur under any circumstances. It should also be noted that the risk of ship-ship collisions is a square function of the number of vessel passages. Thus, when traffic across crossing line D is 10 times smaller than across crossing line E (main route in the area) under otherwise similar conditions, the risk of ship-ship collisions is in fact 100 times lower than on the main route. Thus, there is no apparent need for a TSS organising the northeast- and southwest-bound traffic.

2.3.1.4 Conclusion

The marine traffic analysis concluded that, significantly large international marine traffic passing through the Zone G and Zone E is in potential conflict with offshore wind farm development in these zones. Therefore, it should be considered to establish a TSS in these areas in relation to the Northwest – Southeast direction, for mutual coexistence, with an objective of harvesting maximum possible offshore wind potential at the same time reducing navigational risks as well as avoiding disproportionate detours and traffic disturbances.

Considering the traffic volume passing through the OWF zones in the Northeast – Southwest direction, it was assessed that, a Traffic Separation Scheme is not required. This implies that normal navigation channels without separate directional lanes will be sufficient. These channels can either be placed inside the OWF area or adjacent to the OWF area. The existing shipping traffic could be diverted outside the zones to maximise the offshore wind development, but this decision is dependent on national priorities and a trade-off between offshore wind production yield and prolonged travel time (and CO_2 production) of the ships running in NE – SW direction.

2.3.2 Wind climate

India has a strong monsoon climate characterized by a wind shift from ocean to land (summer) and land to ocean (winter). This pattern can be observed in Figure 2.29 supported by the data plotted as wind roses in Figure 2.28 where 20 years of ERA-5 data is observed.

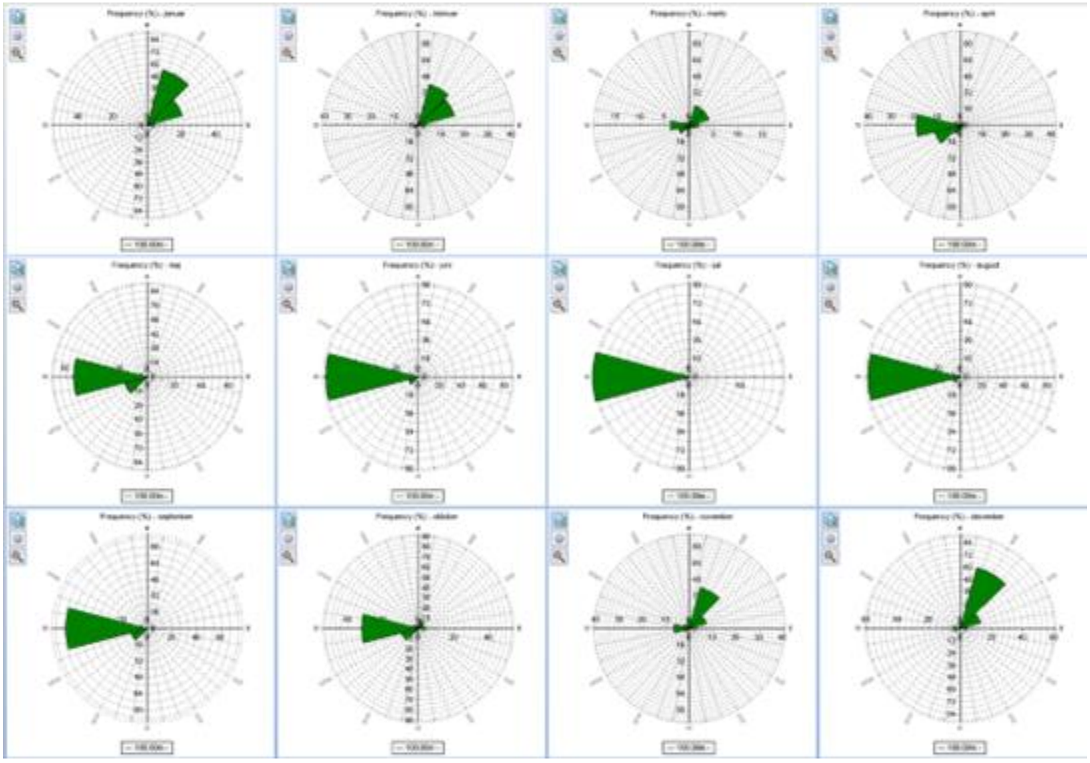


Figure 2.28 – Monthly wind roses based on 20 years ERA-5 data

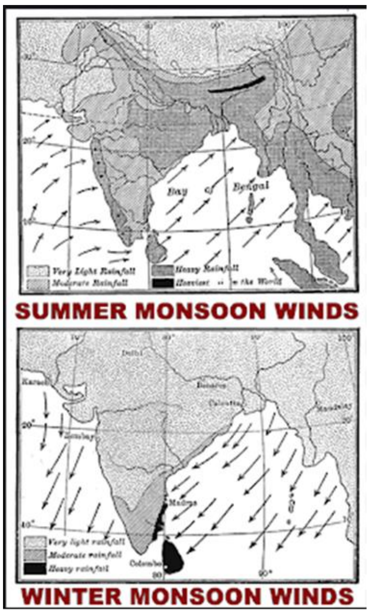


Figure 2.29 - Monsoon wind directions in southern India

During the winter season where most wind is coming from the shore (and from the Bay of Bengal), the existing mountain chain Western Ghats would act as a natural block/wall to the wind, and create the pressure gradient, towards south. The Western Ghats block southwest monsoon winds from reaching the Deccan Plateau. This flow can be observed in Figure 2.30 where the wind resource data is taken from Global Wind Atlas and black arrow representing the mountain chain.

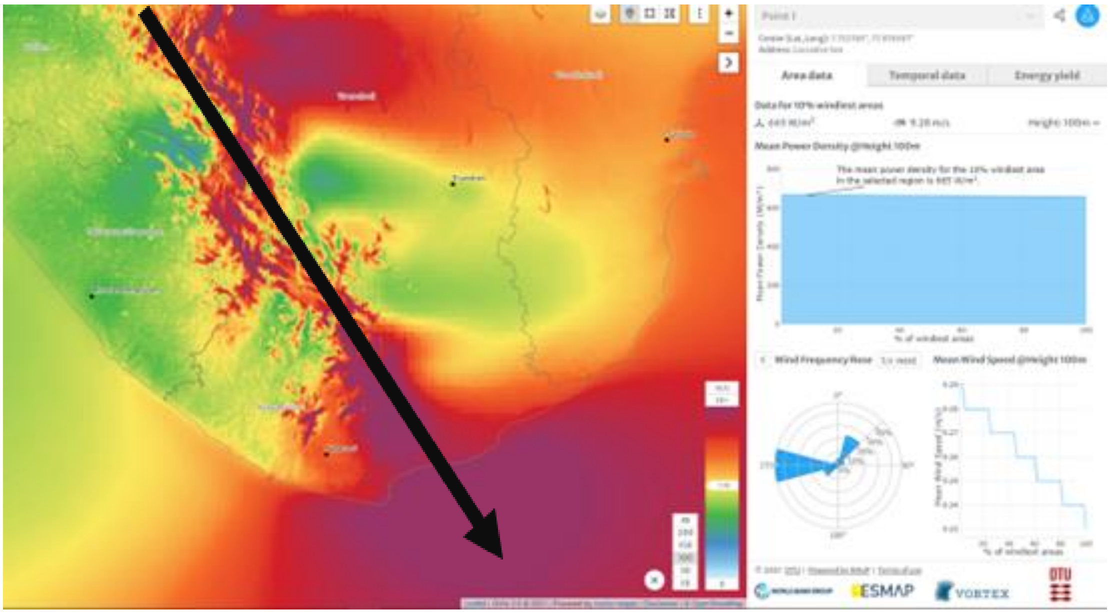


Figure 2.30 - Wind resource data of southern India

As mentioned in the State of Environment Report (SoER) (Department of Environment and Climate Change, Government of Tamil Nadu, 2017) prepared by Department of Environment of Government of Tamil Nadu in 2017, over the period 1891 to 2007, Tamil Nadu was hit by as many as 91 cyclonic storms. Table 2.3 shows the decadal break-up of the frequency of cyclonic storms crossing the northern and southern coasts of Tamil Nadu.

Period	Tamil Nadu North	Tamil Nadu South
1891-1900	3	0
1901-10	4	1
1911-20	4	1
1921-30	9	2
1931-40	12	0
1941-50	10	1
1951-60	8	1
1961-70	10	2
1971-80	3	3
1981-90	2	2
1991-2000	9	3
2001-07	1	0
Total (1891-2007)	75	16

Table 2.3 - Frequency of cyclones in Tamil Nadu (India Meteorological Department, Chennai, 2008)

The season-wise frequency of cyclonic storms crossing the northern and southern coasts of Tamil Nadu are shown in Table 2.4. The North-East monsoon period (October to December) brings maximum number of cyclones to both northern and southern coasts.

Season	No. of Cyclonic Storms (1891-2007)	
	Tamil Nadu North	Tamil Nadu South
CWP	2 (2.67)	1 (6.67)
HWP	9 (12)	1 (6.67)
SWM	0 (0)	0 (6)
NEM	64 (85.33)	13 (86.67)
Total	75 (100)	15 (100)

Note: Figures in parentheses are percentages; CWP → Cold weather period (January – February); HWP → Hot weather period (March – May); SWM → South-west monsoon (June – September); NEM → North-east monsoon (October – December).

Source: IMD (2008).

Table 2.4 - Seasonal frequency of cyclonic storms in Tamil Nadu

Out of the 91 cyclonic storms that hit Tamil Nadu between the years 1891 to 2007, 30 were severe cyclonic storms. There have been 8 severe cyclonic storms having the highest intensity during their crossing from sea to land in the past 30 years in Tamil Nadu (IMD, 2011). Based on this, the annual probability of occurrence of severe cyclonic storms in Tamil Nadu is estimated as 27 per cent, which is considerably large and only slightly lower than that of one other Indian State (i.e. Andhra Pradesh with an annual probability of 30 per cent). Moreover, the widespread destruction of ecosystems, property, infrastructure and loss of human lives due to the 2004 Tsunami demonstrates the vulnerability of the Tamil Nadu coast to natural disasters and extreme weather events. A cyclone hazard map of Tamil Nadu can be seen in Figure 2.31.

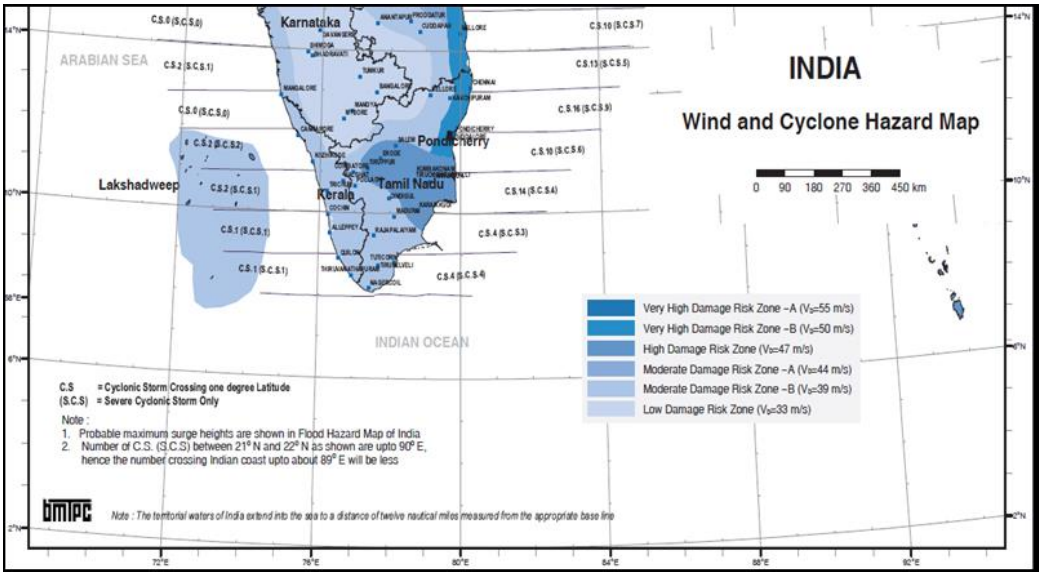


Figure 2.31- Wind and cyclone hazard map of South India. (BMTPC, 2021)

2.3.3 Seabed Screening

This section provides an overview of seabed / geotechnical conditions based on open-source datasets. Unfortunately, there is very limited geophysical / geotechnical data available for the OWF zones in the public domain. Nonetheless, the sections below provide a general overview of existing conditions.

The main available data that has been used as a basis for the fine screening is:

- Bathymetry – grid from Global Wind Atlas (0.25 m resolution) (ESMAP, Global Wind Atlas , 2021)
- Seafloor geomorphology – data from ESRI (ESRI, 2020)
- Faults – data provided by PRDS (PRDS, 2021)
- Seabed features e.g., basins, ridges, and canyons – data from EMODnet (EMODnet, 2021)
- Geology – map from Geological Survey of India (GSI, 2006)

2.3.3.1 Seabed Morphology

The bathymetry offshore in southern Tamil Nadu shows that relative shallow waters are found to the north and north-west (typically 10-25 meters), whereas the waters to the south and south-east are deepening on the shelf to typically 25-50 meters. The -50 m contour line indicates potential areas suitable for fixed wind turbines. It is clear from Figure 2.32, that the slope deepens abruptly into the abyss with more than 1,000 meters depth. However, the assessed area is placed on the shelf and the bathymetry is ideal for offshore wind farms. Based on a very high-level description of the seabed classification (S.K, 2016), the seabed looks most likely to be primarily covered by sand – and locally silt towards the south.

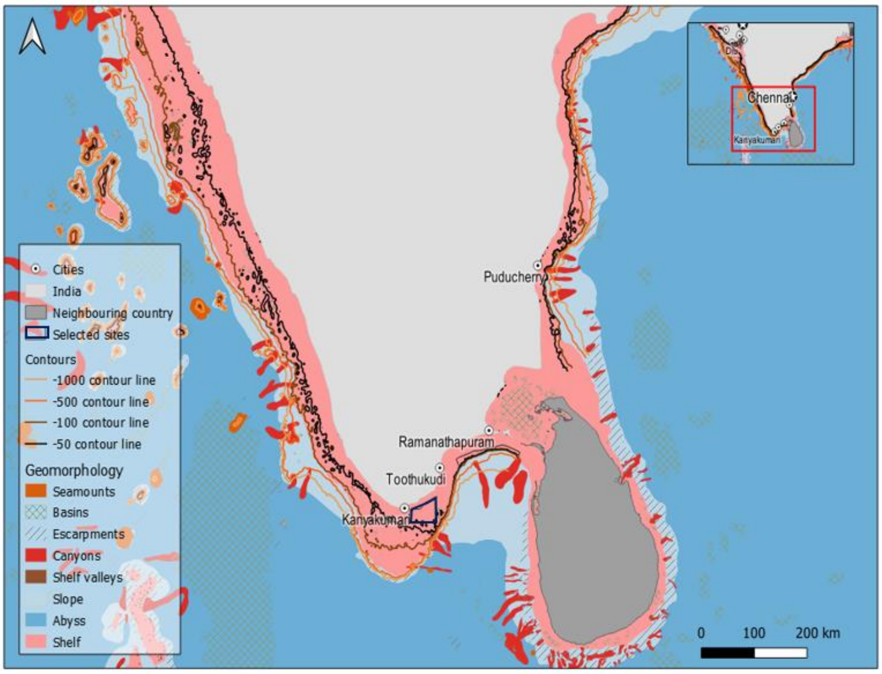


Figure 2.32 - Geomorphology and bathymetric contours in southern India (shortlisted site marked) (ESRI, 2020)

2.3.3.2 Geology

The coastal and offshore areas in the Tamil Nadu region consist of loose to medium dense sand and moderately hard sedimentary rocks ranging in age from Late Jurassic (~ 120 million years ago) to recent and the present day.

In Tamil Nadu (onshore), the western part comprises the continuous range of Hills "Western Ghat" roughly trending N-S direction. The central part of the region is an area of dissected pediments and Pedi plains with residual hills. A coastal plain with associated landforms marks the eastern part (GSI, 2006). Crystalline rocks of Archaean to late Proterozoic age occupy over 80% of the area while the rest is covered by Phanerozoic sedimentary rocks mainly along the coastal belt and in a few inland River valleys. The sedimentary rocks of the coastal belt include fluviatile, fluvio-marine, and marine sequences ranging in age from Carboniferous to Mio-Pliocene and sediments of Quaternary age. For a geological map of Tamil Nadu and Pondicherry see Figure 2.33.

Offshore Tamil Nadu the sedimentary rocks have formed into a series of alternating basins and ridges. The basins (The Gulf of Mannar Basin and Gulf of Mannar Sub-basins) and ridges are controlled by deep crustal faults with vertical uplifts, producing a series of "horst (ridge) – graben (basin)" structures. These ridge-basins (or horst-grabens) are associated with very limited faults structures within the shortlisted site. The main direction of the faults near or within the shortlisted site is NW-SE or SW-NE, (NGRI, 1978) (ONGC, 1993) (PRDS, 2021). Faults are more numerous in the eastern Mannar Basin near Sri Lanka and north and south of the shortlisted site, hence there are not to be expected major fault movements within the shortlisted site.

Overall, the Gulf of Mannar is shown to have an underlying geology comprising of volcanic rocks interspersed with sedimentary rocks and overlain by thick Miocene and recent marine deposits and present-day unconsolidated sediments (Badrinarayanan, 2003). (Ratnakyake, 2017) (Cooray, 1991)

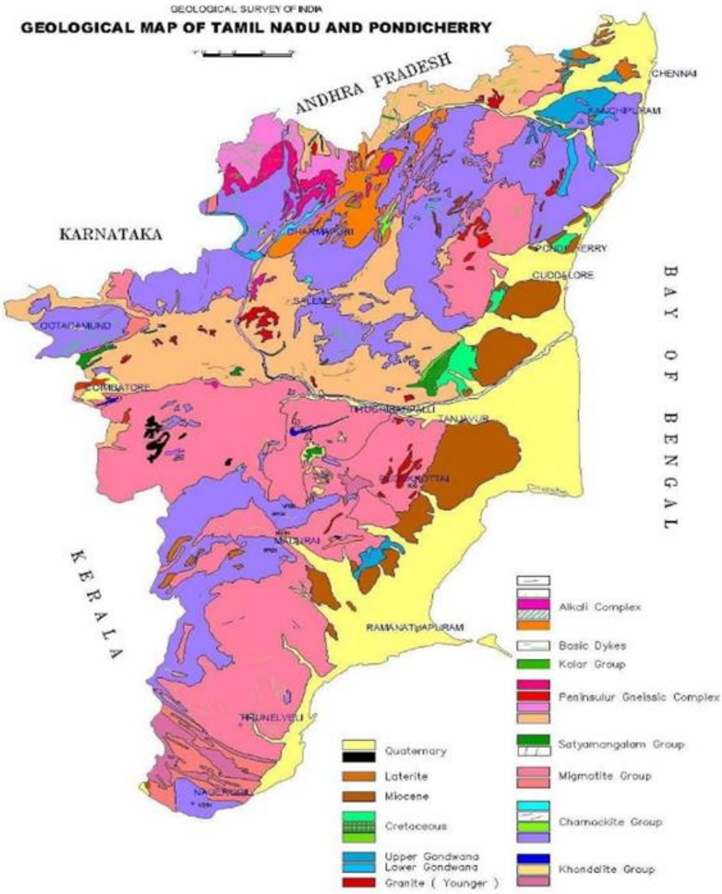


Figure 2.33 - Simplified geological map of Tamil Nadu and Pondicherry regions (GSI, 2006)

The sedimentary geology of the shortlisted site is predominantly part of the 'Gulf of Mannar Sub-basin'. The Gulf of Mannar Sub-basin constitutes the south-eastern offshore part of the Cauvery Basin, the southern most of the Mesozoic rift basins along the east coast of India (FOWIND, 2015). The typical geology is similar to the general geology of the Cauvery Basin, which consists of both Quaternary and pre-Quaternary sediments with various consolidated and unconsolidated properties.

Along the west coast of the Kanyakumari District, a sequence of sandstone and clay with thin lignite seams is recorded. In the western regions of the Gulf of Mannar sand, silt and soft clay marine deposits are found (Saravanavel, 2020).

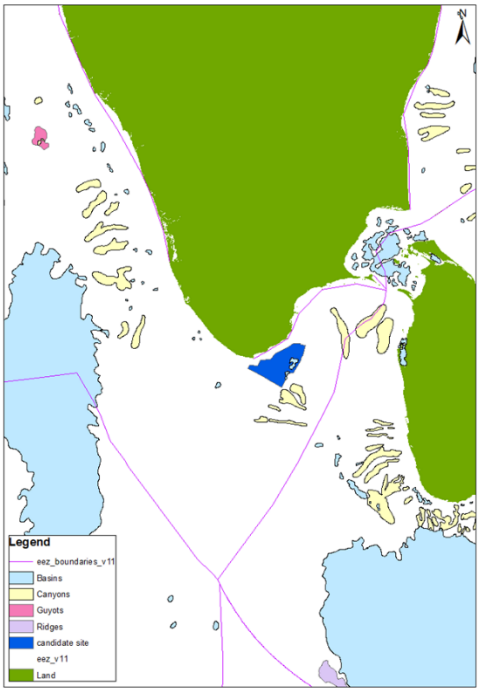


Figure 2.34 - Showing geological features on the seabed offshore southern India

There are no extensive sedimentary basins deposited within the shortlisted site, however a few smaller basins (part of Gulf of Mannar Sub-basins) are deposited within the south-eastern part of the shortlisted site, Figure 2.34. Further offshore (to the south and south-east) there are several marine canyons. The sedimentary cover at the seabed and eroded sediment from the basins probably feeds sediment into the canyons and therefore some sedimentary transport across the area must be expected. The thickness of the sedimentary cover on the seabed is difficult to estimate without geological well control and sampling. The sedimentary cover may vary a lot locally and the presence of sandstones and other sedimentary rocks is expected to be found near the seabed at least within the basin areas. Hence, these areas are not recommended for wind farms until further data have been acquired.

A sub-surface investigation including shallow cores was acquired some 10 kilometers from the coastline of Tamil Nadu, some kilometers north of the northern part of the assessed area. The data is confidential and cannot be referred to but one of the borehole logs in this area identified a 1.5-meter dense to very dense silty sand with shells in the top followed by a 14-meter sequence of highly weathered and fractured calcareous sandstone. Hence the 15.5 meters sub-surface profile is one of the only localized ties for correlation from the onshore geology to the offshore sub-surface geology.

Based on the available data and COWI inside knowledge the subsoil conditions along the southern coast of Tamil Nadu may be classified as Figure 2.35:

- Loose to medium dense sand from seabed to 5 m below seabed
- Medium to dense sand from 5 m to 15 m below seabed

- Moderately strong rock from 15 m below seabed

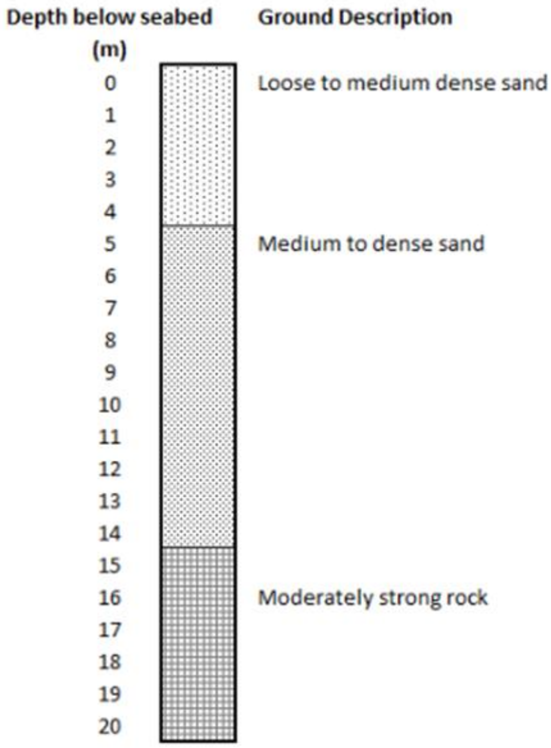


Figure 2.35 - Illustration of stratigraphic profile of what might be expected within the shortlisted site. Note this is a general illustration which cannot be used to plan for foundations, as there will be local variations that are not known at this stage.

2.3.3.3 Geotechnical

The stratigraphy is believed to generally comprise of sand and cemented sands with occasional stiff clay seams to depths of around 45m, with relative density of the sands ranging from loose to very dense. This stratigraphic assumption seems to fit with the confidential shallow cores from north of the OWF site described in section 2.3.3.2 (comprising sand in the top and cemented sand/sandstone below).

Estimated lower and upper bound soil profiles offshore the northern-most part of the shortlisted site suggests a depth of sand dominated sediments down to approximately 21 meters below the seabed (with a friction angle of 20-25 degrees). Below 21 meters cemented sand profiles (sandstone) is expected (with a friction angle of 45 degrees). The lower and upper bound has been provided to estimate a "Rochdale Envelope" of soil conditions for the zone and as such provide a range of possible conditions for foundation concept design (FOWIND, 2015).

The two soil profiles vary quite significantly in terms of competence. The upper bound soil profile represents conditions where cemented ground is present to depth. In terms of soil parameters this is represented by a sand layer with a very high angle of friction. A soil profile of this type lends very strong lateral and vertical support to foundations and is ideal for the deployment of offshore wind, however it may present problems for pile driving. The lower bound soil profile is significantly weaker and features loose sand layers. These loose sand layers may present problems for lateral and vertical resistance. Of considerable uncertainty is the spatial distribution of each soil type. The variation in ground conditions across the zone will be of importance to the applicability of different foundation types, and their relative costs.

To obtain more accurate estimates of soil parameters and stratification in the region, and for any future projects, a detailed site-specific offshore geophysical and geotechnical survey campaign is to be conducted and combined with a comprehensive ground model to capture spatial variability and geohazards across the site.

2.3.3.4 Seismicity

The State of Tamil Nadu has earthquake hazards levels of low to moderate. In the Seismic zoning map of India (Menon, 2010), most of the Tamil Nadu region south of Chennai is classified as Zone 2 "Low Damage Risk". Except for Zone G, all the selected offshore wind development zones fall within this "Low Damage Risk" classification. The earthquake classification in the area surrounding Zone G and much of the Kerala State is Zone 3 "Moderate Damage Risk" (see Figure 2.36).

The selected zones are all located off the south and southeast coast of Tamil Nadu. In a 2010 study (Ganapathy, 2010) the peak ground accelerations across Tamil Nadu have been estimated at 0.08g to 0.21g m/s2 for a 1 in 50-year event (return period of 475 years).

There is no recorded historical seismicity in the order of above 3.5 MW within the shortlisted site. This is very positive, but there are for instance registered seismicity of more than 5 MW to the south-east of the site offshore approximately between India and Sri Lanka.

It is hence anticipated that foundation designs within the Tamil Nadu region will require seismic analysis, liquefaction investigations and analysis of other earthquake hazards.

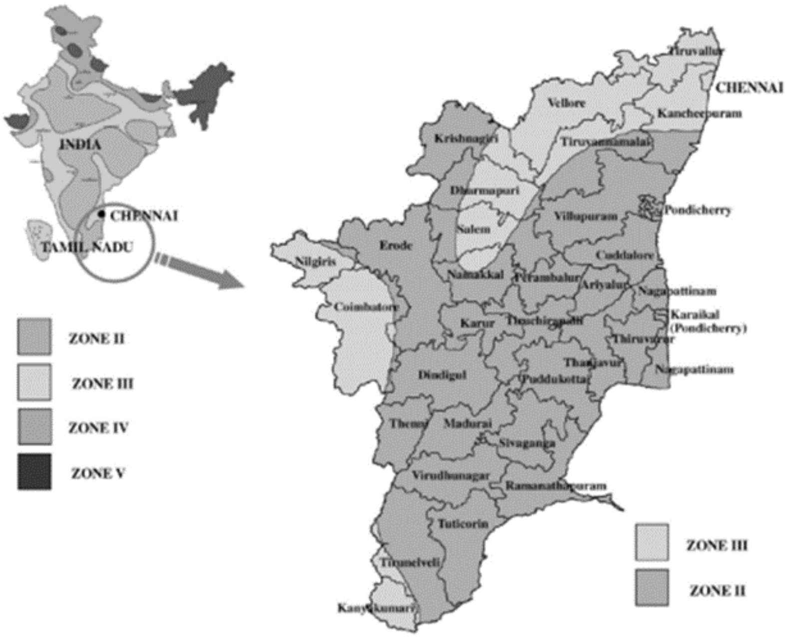


Figure 2.36 - Earthquake hazard risk zonation of the seismotectonic features of Tamil Nadu (Menon, 2010)

2.3.3.5 Conclusion

Based on the available data and literature, the seabed conditions offshore in Tamil Nadu have been assessed at a high level for different geological and geotechnical conditions relevant for construction and operation of OWF such as water depth, seabed sediments, and seismic activity. The general conclusion is that the data available is too sparse and therefore no specific conclusions can be made for the shortlisted sites. However, several recommendations have been made in the following text to help enhance the knowledge of the seabed and sub-seabed conditions.

A general recommendation is to obtain site specific geophysical and geotechnical data to support the further phases of developing the Offshore Wind farm. These surveys will provide knowledge of the seabed and sub seabed conditions. A magnetometer survey is recommended to be part of the geophysical survey campaign. Magnetometer surveys can identify 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 are shallow geotechnical coring and CPT campaign. Testing these conditions understanding of the sedimentology, ground resistance and strength conditions in the subsurface. This will greatly improve the understanding of the area for OWF and help ranking the areas.

Figure 2.34 illustrates that in general no larger subsea structures are expected in the OWF site. However, smaller basins have been identified in the eastern part of the shortlisted site. Basins can consist of various sediment types which can be both unconsolidated and consolidated or a mix of the two. Therefore, it is recommended that both geophysical and geotechnical data is obtained in this area to investigate the subsea soil parameters and stability.

Earthquakes are not considered a major concern because the location of shortlisted site is considered a seismic low risk area. However, section 2.3.3.2 describe the possibility for faults to be present which can influence the seabed stability and therefore further investigations for faults are advised. Furthermore, development of OWF sites close to shore must take into consideration tsunami incidents and especially the potential scour related to low amplitude tsunami waves.

It is also recommended 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 is recommended that Metocean data is obtained so knowledge of sea currents at the shortlisted site can be known. Metocean data can also support a seabed mobility assessment.

General conclusions are that fixed bottom wind turbines are economically feasible at water depths up to approximately 65 m. Floating foundations are possible in various areas except where escarpments on the slope are found. The inserted bathymetric contour line of -65 m can be used as a general guideline for fixed bottom foundations.

The seabed offshore southern Tamil Nadu consists mainly of sand, probably with minor silt dominated areas towards the southern part of the shortlisted site. Whether the upper layers of the subsurface is consolidated and to which state is not known and the geophysical and geotechnical surveys suggested above will bring the project closer to a true fine screening of the area.

2.3.4 Ports and Logistical Infrastructure

The port infrastructure is an essential enabler of offshore wind, which must be fulfilled locally. 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. It is beneficial that their location is as close to the wind farm they serve as possible, but this is not usually a bottleneck, as small regional or even local port / fishing harbour, with some limited adaptations can potentially be used.

2.3.4.1 Construction Port

The rough screening (refer Section 2.2) identified Tuticorin Port, also known as V.O Chidambaram Port (located in town of Toothukudi), as a potential candidate port for supporting the offshore windfarm development in the considered zones.

The Port is an all-weather port and is designated as a major port in India. It is well connected by a broad gauge rail line between Nagercoil and Chennai, and a national highway with all major cities. It appears to have sufficient berthing space as well as dry and secure storage and a broad-gauge rail link and easy access to the national highway system.

Table 2.5 below provides an overview of the features of Tuticorin Port. The Danish Energy Agency's separate port study provides a gap analysis performed for Tuticorin port in order to evaluate its suitability to support offshore wind development in the identified zone of Tamil Nadu.

	Tuticorin Port
Distance to Zones	50-100 km
Depth at channel entrance	9.3 to 14.2 m
Harbour entrance width	150 m
Presence of lock/gate	Not present
Vertical clearance	No restriction
Berth length	140-370 m
Depth at berth	9.3-14.2 m
Load capacity	50-100 kN/m^2 (UDL)
Yard area	15-20 hectares

Table 2.5 - Tuticorin Port properties

2.3.4.2 Operations and 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 (ref. (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 needs to 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.

For Tamil Nadu, 2 viable options for an O&M port are identified, Tuticorin Port (also identified as the Transport and Installation Port) and Chinnamutton. Below are considered some of the requirements for an O&M Port in direct comparison for the 2 selected ports.

Considerations	Chinnamuttom Harbour	Tuticorin
Distance to wind farm	30 km	50-120 km
Harbour entrance width	100 m	150 m
Presence of lock/gate	Not present	Not present
Vertical clearance	120 m-no restriction	120 m-no restriction
Berth length	100-200 m	200-400 m
Yard area	Not clear, potentially limited	15-20 hectares
Road / Rail Access	Medium (through the town centre)	Good
Storage (components and consumables)	Limited (currently a fishing harbour)	Good

Office space / Control Centre	Development required	Potentially good
Potential for expansion to service other windfarms	Limited	Good
Notes / Remarks	Currently a fishing harbour with limited commercial or industrial development	Currently a commercial/light industrial harbour with some infrastructure

Table 2.6 - Summary of port properties for O&M use

2.3.4.3 Conclusion and next steps

The rough screening and preliminary assessment of ports around the shortlisted OWF sites in Tamil Nadu based on open source, confirms that there are potential candidate ports, such as Tuticorin Port, that could potentially support the construction and installation of OWFs.

Accordingly, a detailed assessment / port study has been 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 coast of Tamil Nadu against pre-defined baseline criteria for a construction port and an O&M port.

2.3.5 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 colours 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 2.37. 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 the calculation of LCoE can be found in Appendix A: GIS guide combined with the description of methodology of rough and fine screening.

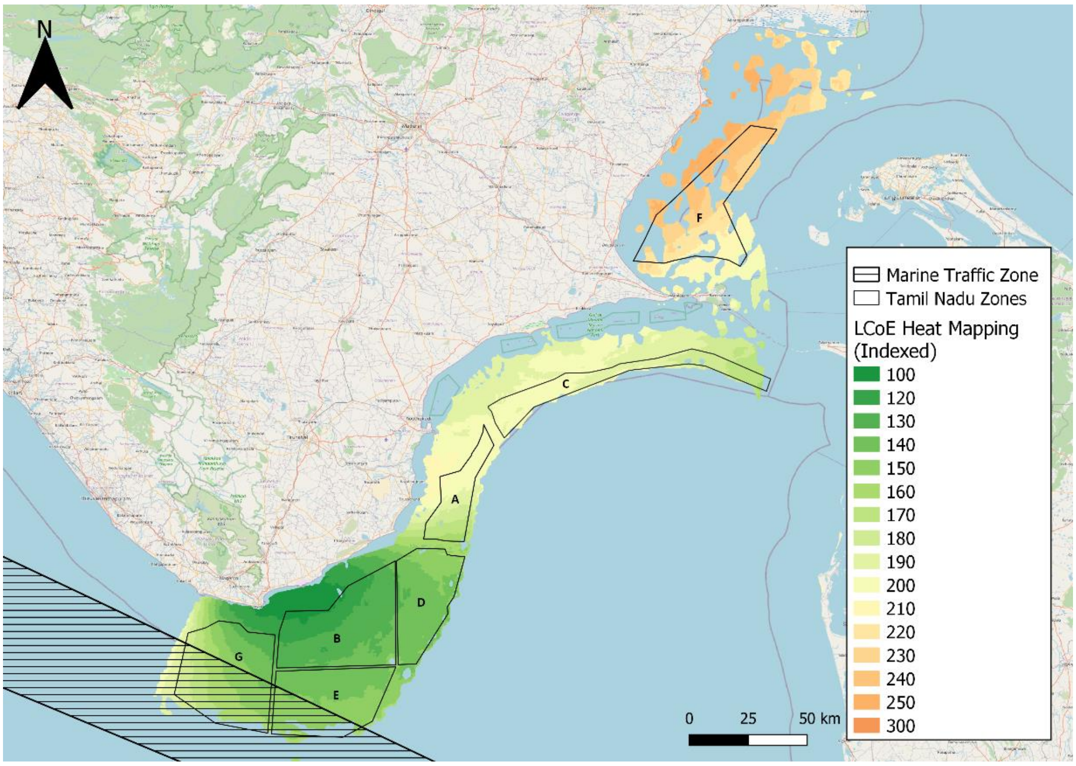


Figure 2.37 - LCoE Heat Map of Tamil Nadu coast

From the figure it can be confirmed that offshore wind zones B, D, E and G are the most suitable zones for development of offshore wind projects. Therefore, conceptual plan and buildout analysis is performed in these zones.

2.3.6 Conceptual Planning Basis

2.3.6.1 Energy Density and Area Requirements

The energy density of an offshore wind farm relates to the cumulative power divided by its area, as well as the spacing between individual wind turbines. Offshore wind farms experience losses by wake and blockage effects. The effect of wind turbine spacing on the wind farm efficiency reduces as wind speeds increase. The efficiency of wind farms in terms of minimizing wake and blockage losses increases with the increase of the wind farm area (Baltic LINes, 2018).

Lower densities will lead to lower losses, but at some point, other effects bring more expenses, such as the intra-array electrical system, installation, cabling, and operation and maintenance. These effects have been modelled, for instance, by ECN wind energy, showing that the lowest LCoE is achieved at capacity densities of 4.7 and 5.0 for 10 MW and 15 MW turbines, respectively, for the offshore Hollandse Kust 3 site in the Netherlands (Figure 2.38).

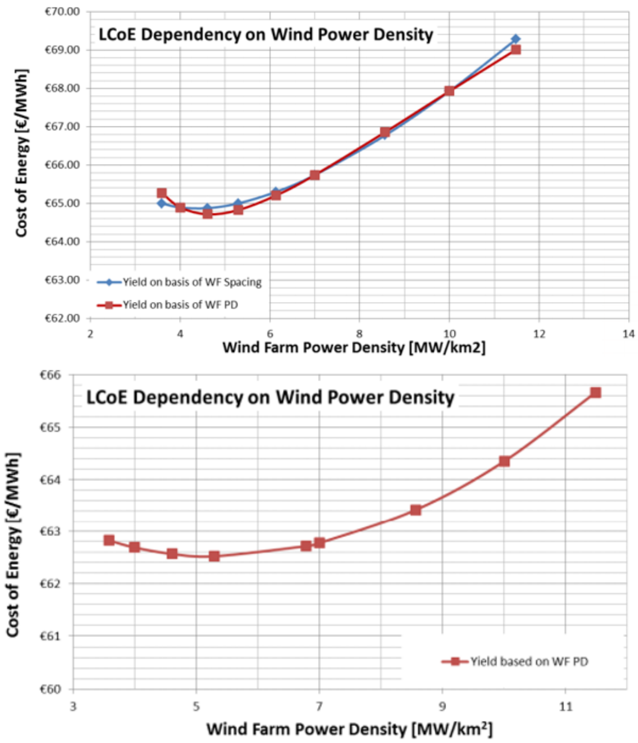


Figure 2.38 - Dependency between LCOE and wind farm power density. The top figure is for 10 MW turbines, the bottom figure is for 15 MW turbines (ECN, 2018).

In general, it is a common interest of the offshore wind industry to achieve the lowest feasible LCOE levels. In this regard, some countries have introduced regulations addressing the energy density in offshore wind tenders to minimize wake and blockage losses. Some examples are discussed in the following sections.

Denmark

Danish sites are abundant in the Northern Sea compared to the size of the country. For the newest offshore wind farm in Denmark, Thor OWF, the installed capacity will be between 800 and 1000 MW. The project will eventually have an area of 176 - 220 km² (depending of the capacity), which means the given capacity density will be 4.5 MW/km².

Figure 2.39 shows an example of how other activities at sea are mapped in Denmark, for which consideration must be taken when developing offshore wind.

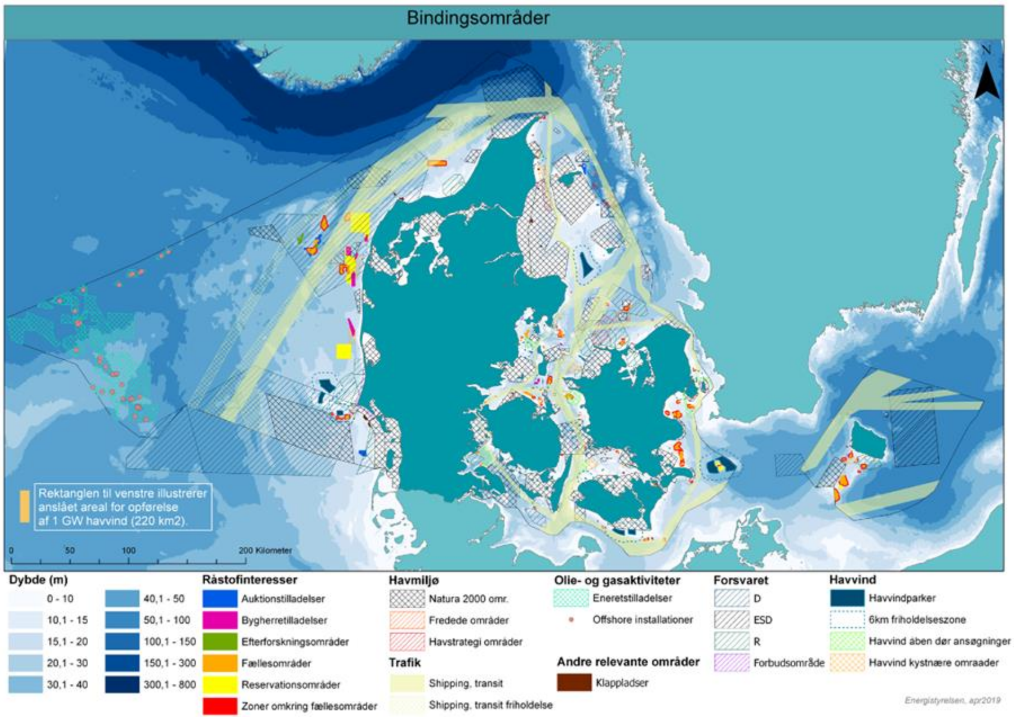


Figure 2.39 - Example of mapping of activities at sea in Denmark (DEA, 2019)

Screening activities for offshore wind development have taken place in Denmark since 1997 and continuously been revised. Today Denmark's maritime spatial plan has been issued as a digital executive order, and the relevant information can be found electronically via https://havplan.dk/en/page/info (see also illustration below).

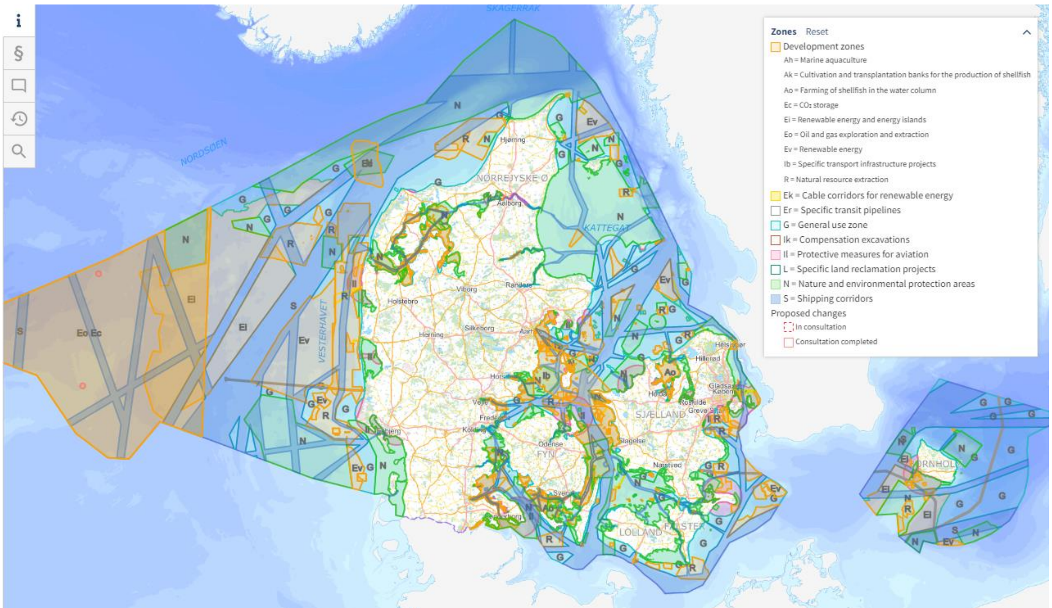


Figure 2.40 – Illustration of Denmark's maritime spatial plan (Havplan.dk, 2022)

The DEA has made screening for 12.4 GW of offshore wind in Denmark and found the optimal LCOE at a capacity density of approximately 4.5 MW/km², equivalent to

220 km²/GW (DEA, 2019). A 30% additional area is required due to site-specific parameters, such as soil conditions, bathymetry, and optimal park layout, increasing this to 290 km²/GW. Another 300% additional area is required for other activities at sea, increasing it further to 870 km²/GW.

The Danish offshore wind farm tenders have in general a low density compared to other countries e.g. Germany and Holland. With the increasing climate targets in Denmark and Europe and increased focus on construction of more offshore wind, the general utilization of the EEZ of Denmark has also recently been in focus and a number of analysis has been carried out. These analysis indicate opportunities for increasing the densities for a better use of the available seabed though this will have an impact on the wake effects. With the higher densities and increased wake effects the analysis in Denmark has focused on identifying the acceptable level of wake losses for the potential future sites, and the initial assessment indicate wake losses of approx. 10% being acceptable, whereas wake losses above 15% would not be acceptable.

Germany

At the beginning of the German offshore wind development, the size, area, and capacity of the wind farm were up to the developer to decide. Due to the fixed subsidies in the Renewable Energy Act, the developer had an incentive to develop wind farms with high capacity, even though this would raise the LCOE.

This practice has stopped in 2017, and new sites up for tender will be pre-determined, with a total installed capacity of up to 1000MW. The sites' properties are presented in a site development plan for the German EEZ. The focus of the new approach is to achieve projects with lower LCOE values (Baltic LINes, 2018). The map shown in Figure 2.41 illustrates the detailed maritime planning that goes into identifying sites for offshore wind.

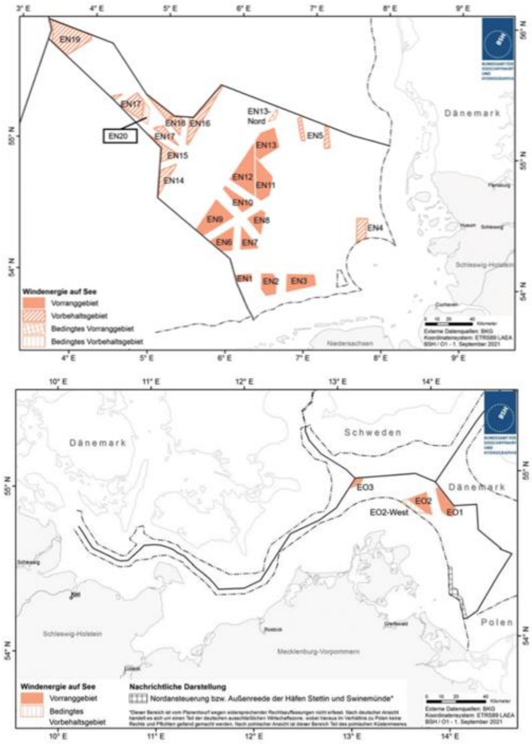


Figure 2.41 - Designated offshore wind areas in the German maritime spatial planning (BSH, 2021)

According to the latest site development plan in Germany, the proposed sites have capacity densities between 8 and 10 MW/km² (BSH, 2020). The high densities in the country are mainly due to heavy deployment and limited availability of offshore wind areas. As a consequence, German offshore wind farms are expected to experience relatively large wake effects.

UK

In the latest offshore leasing round in the UK, four sites were made available for development cf. Figure 2.42:

- Dogger Bank
- Eastern Regions
- South East
- Northern Wales & Irish Sea

Within these areas, the developers were offered the freedom to identify and propose their own project sites and define their optimum capacity, as long as the capacity density stayed above 3 MW/km² (The Crown Estate, 2021). In practice, the smaller wind farms (<500 MW) in the UK have turbine density ~ 8MW/km² and for the larger ones (~1 GW) around 5 MW/km². As in Denmark and Germany, these sites have been identified after detailed maritime planning. A GIS tool to visualize all the maritime activities and regulations is available at (GOV.UK, u.d.; GOV.UK, u.d.).

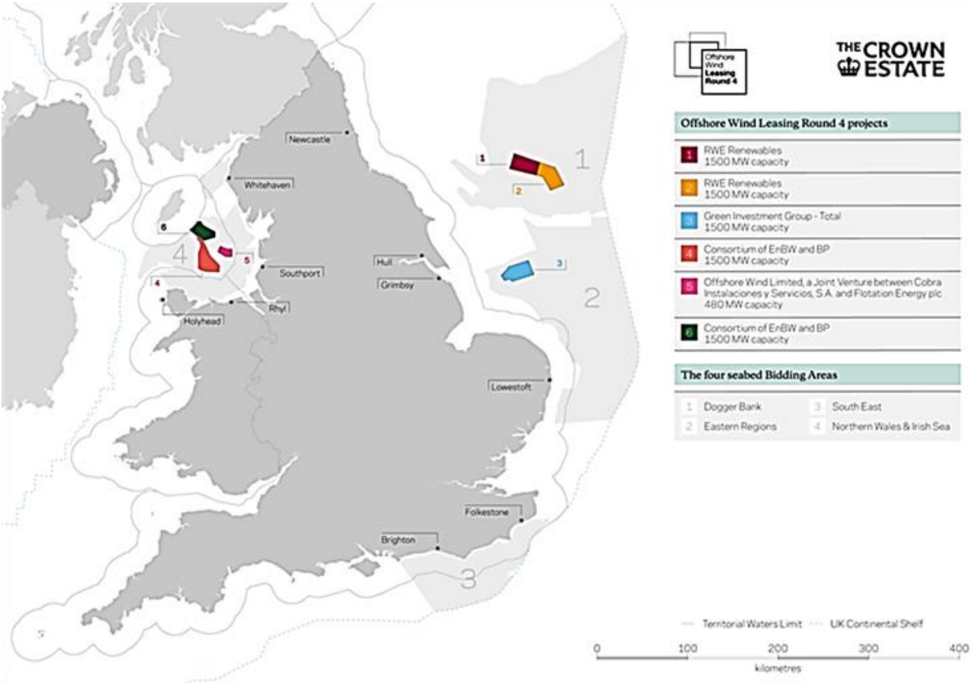


Figure 2.42 - Map of offshore wind areas up for development in the United Kingdom (The Crown Estate, 2021)

In general, it can be seen that an optimal energy density is not just a factor of the spacing between the wind turbines, but a factor of the whole wind park including its area, cabling and balance of plant properties. However, for the size of windfarm being considered in the Tamil Nadu region, and based upon the relatively good wind resources, an energy density between 3-7 MW/km² could be used as a starting point for the design of a project and then fine-tuned accordingly. The relatively low density of 3 MW/km² being considered is very much due to the many unknowns still remaining as no site investigations and environmental surveys has been carried out, and these no site investigations and environmental surveys will of course provide insight to the more specific conditions and potential constraints and risks that needs to be mitigated. The many unknowns and risks still remaining also limits how high a density to plan for initially. At the same time it is also important to make the best use of the most suitable area and ensure harvesting of the maximum potential of wind power in Tamil Nadu bearing in mind the overall national targets.

2.3.6.2 Module Size Considerations

This section aims at identifying an appropriate module size for offshore wind projects in Tamil Nadu. The recent trends in international offshore wind industry / markets suggest a move towards higher capacity wind farms (>500MW), as the economy of scale plays an important factor in reducing the costs (DEVEX, CAPEX and OPEX) and therefore levelized cost of electricity (LCOE). Also, the larger size wind farms are considered more favourable to international developers from an investment perspective.

While considering the CAPEX and OPEX for an offshore wind farm, the electrical power system configuration, although cost approx. 20-25 % of total CAPEX, plays an important role in determining the size of the wind farm, especially when offshore substations are considered. The other costs USD/MW of elements such as Turbine, foundation, balance of plant etc., remain relatively constant despite changes to the farm size.

Therefore, this section attempts to review the cost pr. MW of electrical power system for various sizes of windfarms i.e., 500 MW, 1 GW and 1.5 GW and variation in LCOE (electrical).

Offshore substation (OSS) could be one of the limiting factors, for determining the module size for offshore wind farm. Accordingly, we have made an attempt to study the high-level technical considerations / requirement of various sizes of the windfarms i.e. 500 MW, 1.0 GW and 1.5 GW and prepare a cost considerations (LCOE) for the below scenarios,

- 500 MW with 66 KV export cable systems (without OSS)
- 500 MW with OSS
- 1 GW with OSS
- 1.5 GW with OSS

500 MW WITH 66 KV EXPORT CABLE SYSTEMS (WITHOUT OSS)

A high-level topology for this arrangement is shown in the figure below. 66 kV sea cables are assumed routed from the first WTG to landfall where a 66/230 kV ONSS is located as close as possible to the coastline. An onshore ≈18 km 230 kV 2-circuit interconnector between OnSS and Grid SS is anticipated with 50% OHL and 50% underground cable systems.

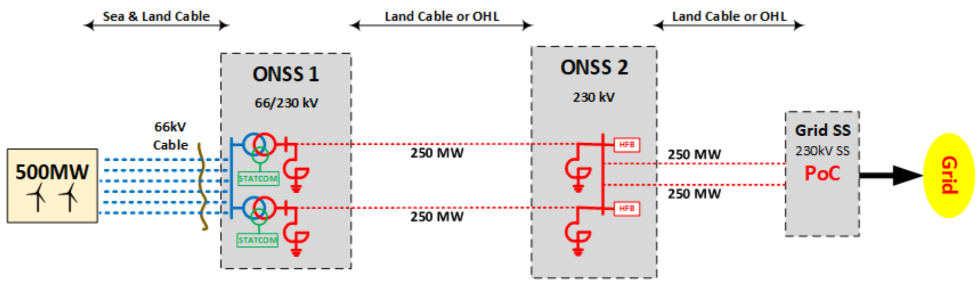


Figure 2.43 - High level topology for 500MW (without OSS)

500 MW WITH OFFSHORE SUBSTATIONS

A high-level topology is shown below.

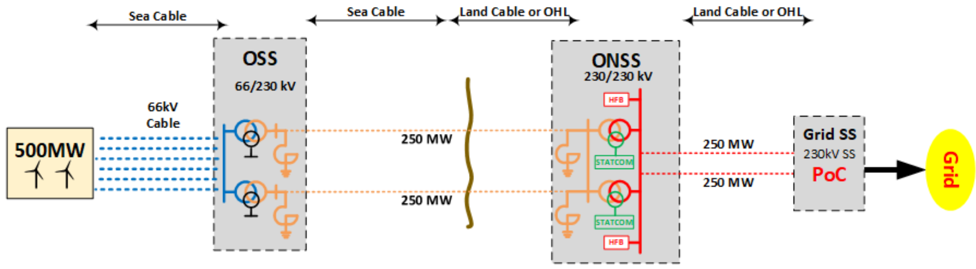


Figure 2.44 - High level topology for 500MW (with OSS)

The OWF power infrastructure comprises:

- one 500 MW OSS is anticipated at the centre of the first WTG row and connected with 6 IAC strings
- Two 230 kV sea cable circuits to landfall each ≈19,5 km
- Two ≈4 km 230 kV cable circuits
- ≈4 km 230 kV double circuit OHL
- One onshore substation next to the Grid SS
- ≈0,5 km 230 kV double circuit OHL/UG Cable circuits
- Two new 230 kV line bays in existing Grid SS

1000 MW WITH OFFSHORE SUBSTATION

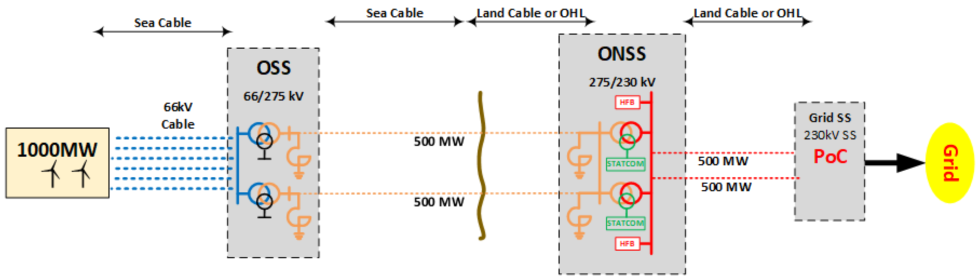


Figure 2.45 - Considered high level topology for 1 GW OSS

The OWF power infrastructure comprises

- one 1 GW OSS is anticipated at the centre of the first OWF site and connected with 12 IAC strings
- Two 275 kV sea cable circuits to landfall each ≈23,5 km
- Two ≈4 km 275 kV cable circuits
- ≈4 km 275 kV double circuit OHL
- One ONSS next to the Grid SS
- ≈0,5 km 230 kV double circuit OHL/UG Cable circuits
- Two new 230 kV line bays in existing Grid SS

1.5 GW WITH OFFSHORE SUBSTATION

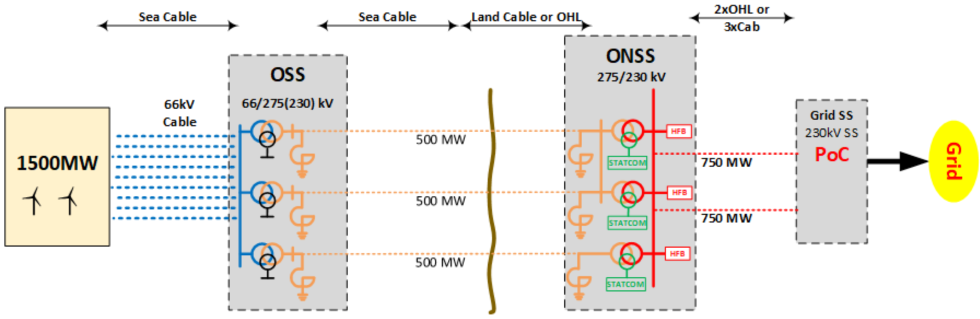


Figure 2.46 - 1.5GW OSS

The OWF power infrastructure comprises

- one 1.5 GW OSS is anticipated at the centre of the first OWF site and connected with 12 IAC strings
- Three 275 kV sea cable circuits to landfall each ≈23,5 km
- Three ≈4 km 275 kV cable circuits
- ≈4 km 275 kV triple circuit OHL
- One ONSS next to the Grid SS
- ≈0,5 km 230 kV double circuit OHL/UG Cable circuits
- Two new 230 kV line bays in existing Grid SS

CAPEX SIMULATIONS

The CAPEX and LCoE assessment implemented for the scenarios discussed above show that purely from the electrical perspective, size of the OWF is likely to have little effect on the overall LCOE. Therefore, the practical consideration such as supply chain and logistical infrastructure and market / commercial dynamics would play an important part in consideration of appropriate size.

Based on this high-level assessment and the very preliminary electrical topologies and concept design consideration, no conclusive recommendation on optimum OFW sizes has been identified, and as such it is concluded that this cannot be justified with offset in the power electrical infrastructure only.

For India as being an emerging market within offshore wind it could initially be assumed favourable considering OSS sizes in the range of 500-750 MW as this is a well-developed and proven design now. However larger offshore substations can be considered during further build out of offshore wind in India but still bearing in mind that larger offshore substations involve significantly more complex design, more excessive weight and more complex inter array cable installation. Accordingly, the supply chain considerations may also restrict the size of offshore substations, but also considering the development timeline and time horizon for actual procurement project sizes of approx. 1000 MW can be considered also bearing in mind the importance of economy of scale, which is foreseen to gradually increase in windfarm size as the local supply chain becomes more matured and experienced.

2.3.6.3 Turbine Suitability Assessment

Energy output on two typical offshore turbines has been assessed based on available information on wind turbines technology (such as power curves and hub heights). The assessment goal is to identify preliminary potential wind turbine types suitable for the wind regime at Tamil Nadu.

In order to estimate the energy production outputs, the following information is required along with the wind climate, previously described in section 2.2.1 :

- Turbine type
    - Rated power
    - Hub height
    - Rotor diameter
    - Power curves
- Site description and digitalized maps
    - roughness and orography data
- Wind modelling computer program
    - WindPRO 3.5 and WAsP 11

For the wind regime data, one data point was extracted from GWA dataset as considered representative for the area.

Two different turbine types are used for the comparison using internal available information of power curves for the Vestas V236-15MW and the SG 200-11MW (updated to 11.5MW). Due to lack of publicly available power curve information on additional turbine types, only calculations related to these turbine types have been presented.

Based on the available wind data, the power curves and the general information of the terrain, an estimation of the expected AEP is made for the two turbine types. For consistency reasons, both turbines have the same coordinates, thus the modelled wind condition is the same for both of them.

The presented AEP values are based on calculations performed by the WAsP linear model. The results are presented below in Table 2.7. Furthermore, the table shows the number of full load hours, wind speed at hub height and the capacity factors. All results are GROSS (stand-alone turbines) and use 150m as the hub height.

WTG Model	GROSS AEP	Capacity Factor	Full Load hours	Mean wind speed at 150 m
	[MWh/y]	[%]	[Hours/year]	[m/s]
XX-200-11.5 MW	66,433	68.9	6,039	10.7
XX-236-15 MW	91,686	69.7	6,112	10.7

Table 2.7 - Production estimate and other key figures for the turbine's comparison

As can be noted, the Gross Capacity Factor is higher for the turbine with nameplate capacity of 15MW, and this preliminary result confirms the high resource availability, but as well a good adjustment from the two WTG technologies to site conditions.

In order to estimate the energy production delivered to the grid, some losses must be considered, such as internal and external wake losses, turbine availability, grid availability, transformer and line loss, environmental etc. This is not considered within the scope of this exercise.

The turbine with the nameplate capacity of 15 MW has been chosen as a suitable shortlisted turbine for further calculations and assessment under marine spatial planning for Tamil Nadu e.g. in relation to estimating external wake losses.

2.3.6.4 Electric Power Connections and Export Configurations

The electrical power systems network is a critical component of renewable energy planning and therefore, it is important to understand the current grid networks and planned initiatives, to assess the opportunities and bottlenecks in relation to integration of variable renewable power from offshore wind. Section 2.2.5 provided an overview of the electrical national grid and have mapped the various substations (with varying kV ratings) that are in the vicinity of OWF zones in Tamil Nadu. This section provides further analysis and discussions on the options for electrical grid connection and possible export system configurations for future offshore wind farms in the area south of Tamil Nadu coastline.

Further, the regional backbone power grid (400kV and above) is shown in Figure 2.47 where also preliminary connection points are indicated. It is pertinent to mention that existing 230 kV substations shown in Figure 2.22 and 110 kV substations could be potentially a viable option for grid connection of smaller OWF's. For example, a 220 kV substation (SS) can receive 2 x 500 MW export cables from "far shore OWFs" and 110 kV can receive several 66 kV export cables from "near shore OWF", subject to availability of balanced (unutilised) capacities at the respective substations.

Figure 2.47 - Regional Backbone national grid (400 KV and above)

OWF Power System Requirements

The OWF power system infrastructure requirements will depend on a number of factors, such as:

- Installed capacity [MW] of the windfarm site
- Distance to the Point of Connection (POC) at an appointed grid substation
- Voltage level required [110kV, 230 kV or 400 kV] at PoC

According to the strategy paper released by Ministry of Renewable Energy in July 2022, evacuation of power from the substation of the developer to the onshore meeting/interconnection point (PoC) shall be the responsibility of PGCIL. The developer shall set up the offshore wind project(s), including the offshore substation at the voltage level of 220 kV, where the metering for the purpose of energy accounting shall be done at the offshore substation. A representation of this setup can be seen in Figure 2.48.

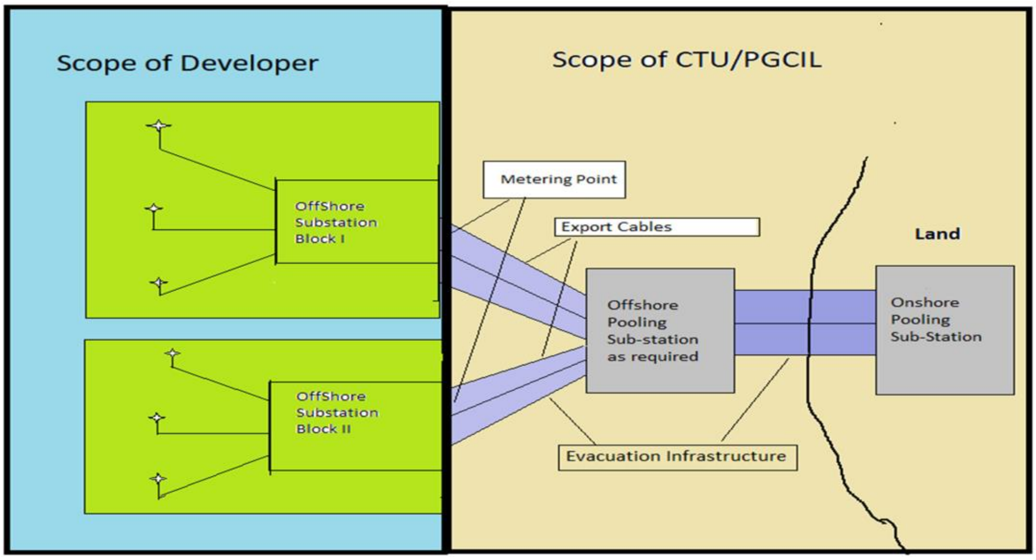


Figure 2.48 - Evacuation Infrastructure Network for Offshore Wind Farms

The regional (TANGEDCO) and / or national grid (Power Grid) operators would be responsible for identification / establishment of PoC and necessary reinforcements in the existing backbone transmission grid. This will undoubtedly require Energy Master Planning and power system studies implemented by relevant Indian stakeholders.

Power system studies from TANGEDCO 2016 suggests that the grid is prepared to absorb 500 MW OFW generated power in 2021-2022. The grid reinforcement program suggested in the referenced study that the planned upgrades would allow for a further 800 MW in 2025 and 2500 MW in 2032. (Allowing total ≈5 GW OFW installed in 2032)[2].

The power infrastructure of offshore wind farms comprises a mix of below components:

- 66 kV array cables from the WTGs
- Offshore substation
- Export cable systems to shore
- Landfall of sea cables
- Overhead line or land cable systems
- Nearshore transformer station
- Interconnector to Grid Substation Location (OHL or UG-Cables)
- Windfarm substation close to Grid Substation
- TSO’s Extension of Grid Substation
- (TSO’s Reinforcement of back-bone transmission power grid)

[2] Later updated studies very likely will contribute with improved intelligence.

The following section describes the key considerations for connecting potential offshore wind farms to the national / regional grid, depending on the size of the windfarm and distance from the PoC. The options considered includes:

- 66KV connection to the shore. This applies to windfarms located closed to the shore
- HV offshore cables from offshore substation
- HVDC grid connection extended to the sea (using power island)

66 KV export sea cables to the shore

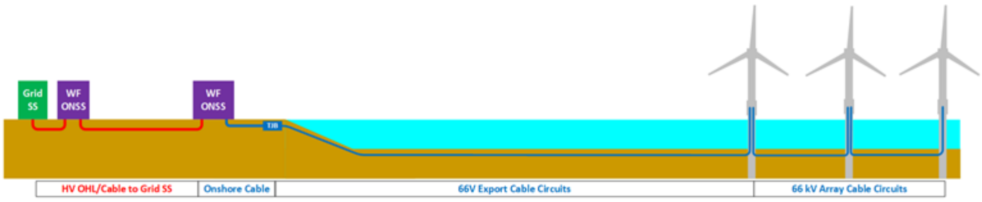


Figure 2.49 -66KV export sea cable concept

This concept can be applied for windfarm sites situated approximately up to 20- 30 km from the shoreline. It is noted that, the technical limit for 66 kV cable circuits is ≈40 km. This concept can be adopted for a large strip of area along the coastline as indicated in Figure 2.50. The voltage could also be raised from 66 kV to 110 kV or 220 kV at the nearshore substation and connected to the transmission grid either via OHLs or cable systems.

This concept today is preferred for many OWF projects in Japan where sites far shore cannot be implemented unless floating WTG's are used.

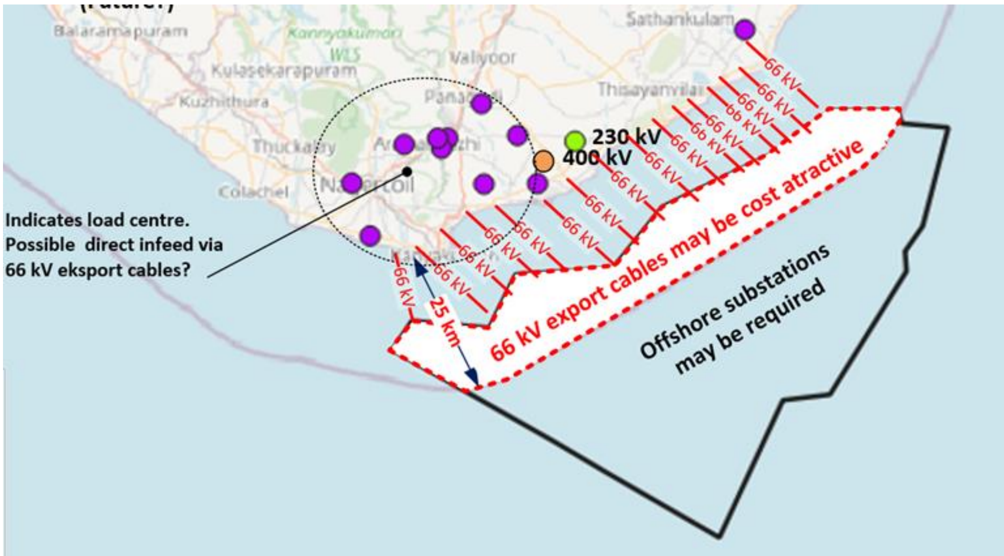


Figure 2.50 - Conceptual 66 KV connection to nearshore windfarms

The key limitation of this approach is that this could only be applied to suitable area for the "near-shore" windfarms, within territorial waters. Also, such an arrangement would require multiple connection points and significantly large number of export cables to the shoreline and many landfall connections.

The key benefit is omission of the OSS both in relation to CAPEX & OPEX (will require offshore maintenance, anticipated shorter construction timeline and far less interfaces to manage during design/procurement/execution). The OWF power could be injected direct into several 110 kV SS anticipated being close to "domestic load centres".

One significant drawback is many 66 kV export sea cables that shall be routed to shore and the higher energy losses in the many 66 kV cable circuits. Eventual challenges in identifying suitable plots for the 66/110(230) substations very near the coastline also shall be mentioned.

HVAC Export Sea cables from an Offshore Substation

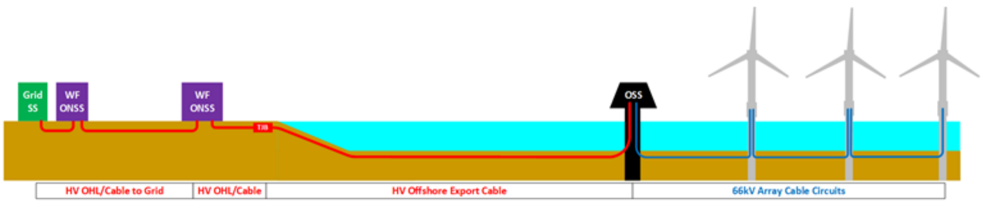


Figure 2.51 - HVAC export cable from offshore substation

OFW's located further than 25 km from the shoreline will be cost attractive with an OSS that connects with the WTGs though 66 kV array cables and to the grid substation via a HV-system. The concept is appropriate up to ≈60 to 80 km sea cable (depending on the voltage level). At longer cable length an offshore substation (OSS or alternatively known as an Offshore Reactor Platform (ORP)) must be constructed in the middle of the export cable corridor.

The OSS will comprise 66/220(275) kV power transformers and reactive power compensation equipment to balance out the capacity charging current of the long HV export cables. An unmanned OSS is the most common design. OSSs today are designed up to 1300 to 1400 MW by developers for projects in Europe and US. An OSS design with helicopter access (HeliPad) and/or accommodation facilities has also been selected by some OWF developers. This naturally will have impact on the tonnage, consequently the requirements for cable installation vessels.

Conceptual power system infrastructure concepts & Point of Connection (PoCs) are illustrated below in Figure 2.52. The PoC allocation must be agreed with the TSO. Comprehensive Energy Master Planning and Electrical Power System Studies to determine necessary regional and national build-out of the backbone transmission grid will be mandatory prior to allocation of PoC for these large OWF projects.

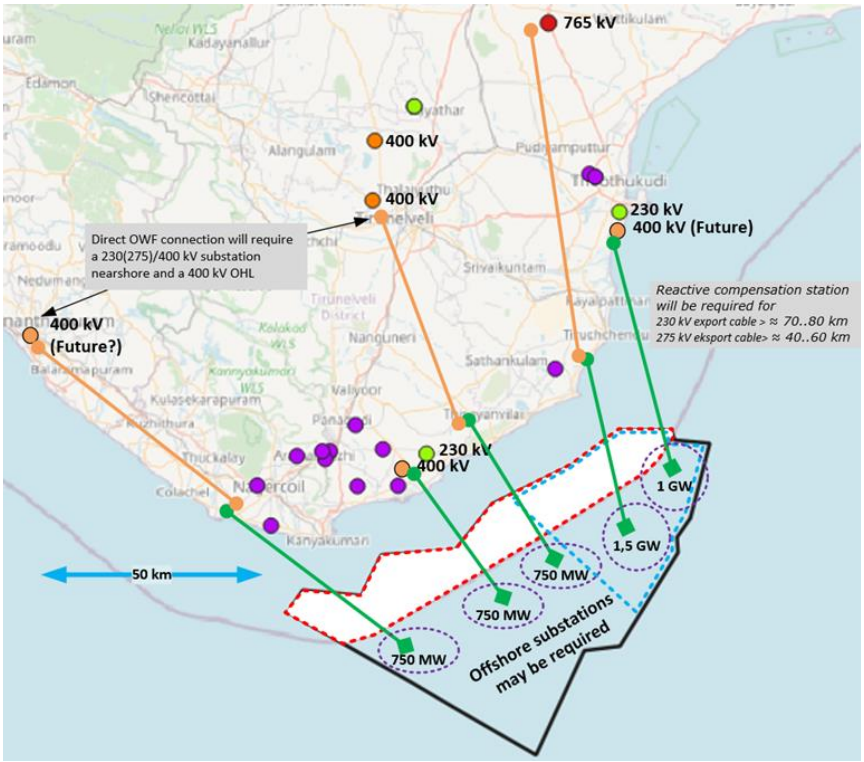


Figure 2.52 - Conceptual HVAC export cable connection to nearshore windfarms

One limitation is distance from shore. (Since requirement for an OSS or an Offshore Reactor Platform (ORP) could make a business case unattractive for private developers). The number of HV export cables (normal is two/three ≈ 400 -500 MW for each OSS) also could be challenged for OWF sizes > 800 MW if unfeasible site conditions impose a 3rd or 4th cable circuit adding CAPEX.

Challenging grid code requirements from the TSO on voltage stability and quality (Harmonic distortion) also could impose costly HV equipment at the OSS and onshore substation.[3]

A benefit is less sea cables approaching the shoreline. An onshore substation very close to the coastline may not be demanded. Annual energy losses in the power system will be reduced compared with the 66 kV export cable concept.

An important consideration is the timeline requested for FEED / procurement / fabrication / T&I of the OSS. The number of installation vessels worldwide being suitable for the topside lift is limited. This could impose high T&I cost until more vessels are available on the market.

[3] Solutions with reactive power compensation plant (both fixed and fast response solutions) and harmonic filter banks already exist in the marked will require large spaces within the onshore substation plots to be identified by the OWF developer.

Identifying shipyards in India with suitable knowledge for OSS design and construction may not exist on a short timeframe.

PoC's located inland (far from the coastline) will have 400 kV OHLs as a preferred design. This could have substantial impact on the timeline since environmental impact assessments, agreements with plot owners and consent from responsible authorities often require a very long timeframe. On this note it shall also be mentioned/considered if the TSO or the OWF is best suited for this complex planning/consenting process.

400 kV underground cables in longer lengths will demand heavy reactive power compensation plants in the ends and along the cable corridor consequently being cost unattractive. The TSO also will be facing a maximum permitted length of 400 kV cable circuits in his power grid, since the transient/dynamic stability will be challenged.

HVDC Grid connections

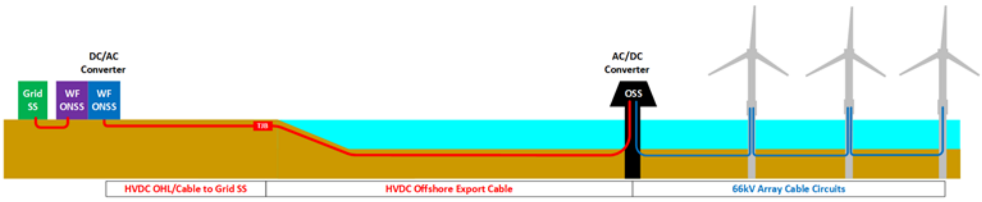


Figure 2.53 - HVDC export cable from offshore substation

HVDC technology allows for transmission of large bulk power over almost unlimited distances and with substantial less power losses in the cable /OHL circuits.[4] Consequently, this approach could be useful if/when the existing/future AC transmission grid is congested or if extension of exiting grid substations constitutes a barrier for OWF grid interconnection. HVDC interconnectors can also be used to transmit power direct from the OWF sites to major load centres in other states of India.

HVDC interconnectors today are Point-to-Point connections. The technology for meshed HVDC grid is not yet mature on large scale but can be anticipated being developed and tested within the next decade.

The HVDC technology is not considered first option for the OWF sites. However, it can be factored in when a long-term grid- and really large scale OFW buildout plans (> 5 GW) are formulated.

Initially the HVDC approach can be considered as:

[4] Power losses in the AC/DC &DC/AC Converter stations will be significant since also cooling plant power consumption shall be taking into consideration. The power losses at long distances however will be significantly reduced when HVDC technology is adopted.

Individual 1 to 1.5 GW HVDC PtP grid connections for the last OWF site developments at largest distance from the coastline that might be connected to grid substation further inland (The most attractive grid SS close to the shoreline will be utilised for the previous OWFs).

1 to 2 GW HVDC PtP solution from an offshore powerhub (presumable on an artificial island) where several OWF's are connected with an aggregated installed capacity reaching 5 to7 GW.

Indicative grid connection concepts are illustrated on the following map.

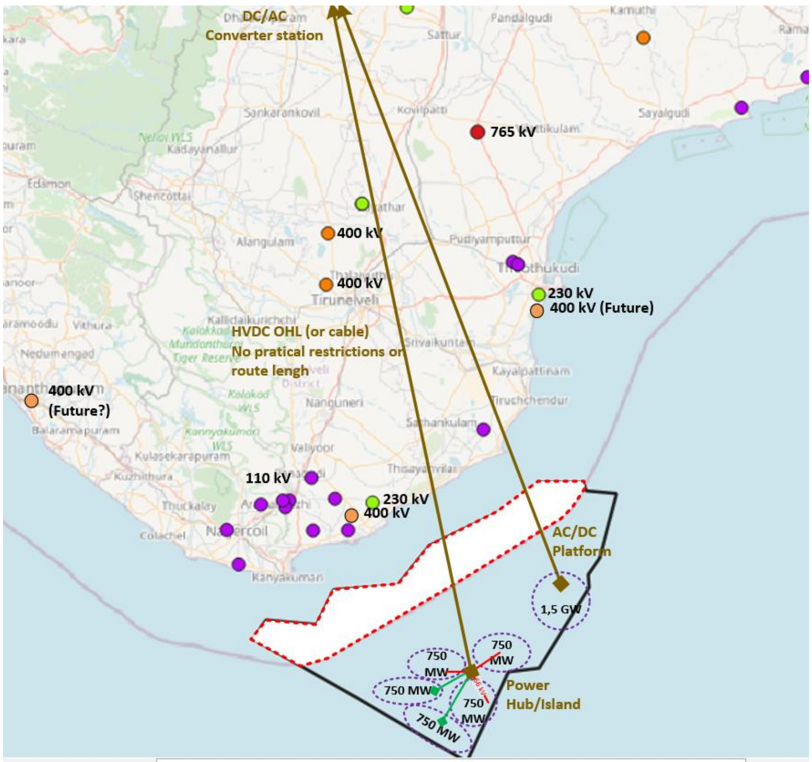


Figure 2.54 - Conceptual HVDC export cable connection to nearshore windfarms

The PtP HVDC grid interconnections can be designed/built/operated by the OWF developer. The power hub and it's PtP grid interconnectors however is considered as a back-bone transmission asset that can be provided by either a private investor or the TSO's on a regional/national scheme. The viability of both approaches will depend on a committed plan for OWF development and the grid's ability to receive and absorb the OWF power produced.

The energy island also could serve as part of a power interconnector between India and Sri-Lanka in the future.

Limitation is establishing a viable scheme for investors[5] for the construction of the energy hub including a national commitment on the required buildout of OWF

[5] Unless the TSO take this responsibility

installed to make the energy hub feasible. The selection of a most viable grid connection of individual 750 to 1500 MW OWF if no power hub is established will likely point to an AC OSS (on the condition that a suitable grid connection substation close to the coastline can be appointed).

Benefit is ability to transfer the OWF power (1 to 1.5 MW OFW sites) direct to load centres far from the south India coastline. Utilisation of the sites far away from the coast lines might be more cost attractive (under the assumption that grid substations close to the coastline is congested and not can be made available). HVDC OHL/Cables are very cost attractive compared with AC systems. An energy island can be reused compared with HVDC & AC transformer platforms that will have a limited lifetime 25 to 35 years.

Drawback is complex and costly HVDC transformer platforms and converter stations onshore. Substantial cost for construction of the energy island and belonging power systems. (Feasibility studies on energy islands approach vs. PtP HVDC OFW is advised)

Design, manufacturing and installation of the HVDC platforms are longer than AC platforms (2-3 year compared with 3-4 years). Construction of an energy island and the HVDC interconnectors to the grid will be 6 to 9 years thus heavy investments shall be made before OWF's are connected and revenue from energy sales can be expected for the energy hub and HVDC transmission investor/operator.

Given the large investment cost and impact on the Indian power system, also with respect to energy supply reliability and safety, only very comprehensive planning, feasibility studies and power system analyses will reveal a most optimal approach for eventual HVDC solutions in a combination with > 5 GW OFW. Today options for energy islands are being investigated and planned in Europe and South Korea as an alternative to PtP AC or HVDC connection of OWF rated > 1 GW.

Conclusion

Based on the evaluation of various alternatives for power export to the shore, it appears that a 66 KV connection without OSS could be an attractive option from a CAPEX perspective. However, this approach would require multiple export cables to the shore and need for multiple landfall locations. This approach would clearly, increase the risk of potential conflicts with environmental and social receptors (such cultural / tourism areas, marine traffic etc) as well as would require significantly increase number of land parcels on the coastline to acquire for establishing the landfall points.

Accordingly, HVAC export cables from an OSS appears to be preferred solution for now, especially for early phase development projects. A modified version of this concept has been mentioned in the strategy paper released by Ministry of Renewable Energy of India in July 2022. In that version, HVAC cables coming out of the offshore wind farm site were not being directly connected to PoC onshore but instead were connected to a pooling OSS. It is in the responsibility of CTU and PGCIL to connect to shore from that pooling OSS.

Power hubs and energy islands are evolving concepts and merit considerations in future for the windfarms located at significant distance from the shore. These concepts are likely to become more relevant when India moves towards floating wind turbines and plans to harvest wind potential from the deeper areas within its Exclusive Economic Zones (EEZs).

2.3.6.5 External Wake Losses and distances between wind farm sites

In this section, a preliminary approach to derive the impact of distance between 2 windfarms depending on the separation distance is being conducted. For this purpose, the external wake losses between two 1 GW wind farms, being separated with a distance varying from 10 to 50 times the rotor diameter were assessed.

According to MEASNET (MEASNET, 2016)(International Network for Harmonised and Recognised Measurements in Wind Energy) recommendation, all wind turbines located within at least 20 times the rotor diameter of the wind turbine in consideration need to be considered. It is also recommended that for large neighbouring wind farms, both onshore and offshore, this radius (i.e., 20 RD) should be extended.

In order to estimate the energy output and the external wake losses, the information and methodology previously described in 2.3.6.3 were applied.

The calculations are made in WindPRO with the WAsP 11 model. N.O Jensen's (DTU/EMD) wake loss model with an offshore wake decay factor of 0.050, which is recommended by DTU for offshore wind farms, has been used to calculate shadow loss. It should be mentioned that for large offshore wind farms, in some areas, there may be a greater shadow loss than what the model used indicates. It has been assessed that the calculated shadow losses are sufficiently accurate for a relative assessment.

The assessment assumed gridded layouts i.e., each wind farm consists of 70 Vestas V236 15MW, with a spacing of 7 RD in the predominant wind direction (downwind - West-East), and 5 RD perpendicular to the predominant wind direction (crosswind - North-South). The turbine distancing 5 x 7D was selected in order to allow allocating several clusters (up to 7 x 1GW wind farms). Figure 2.55 illustrates the above-mentioned distance definition and wind farms configurations.

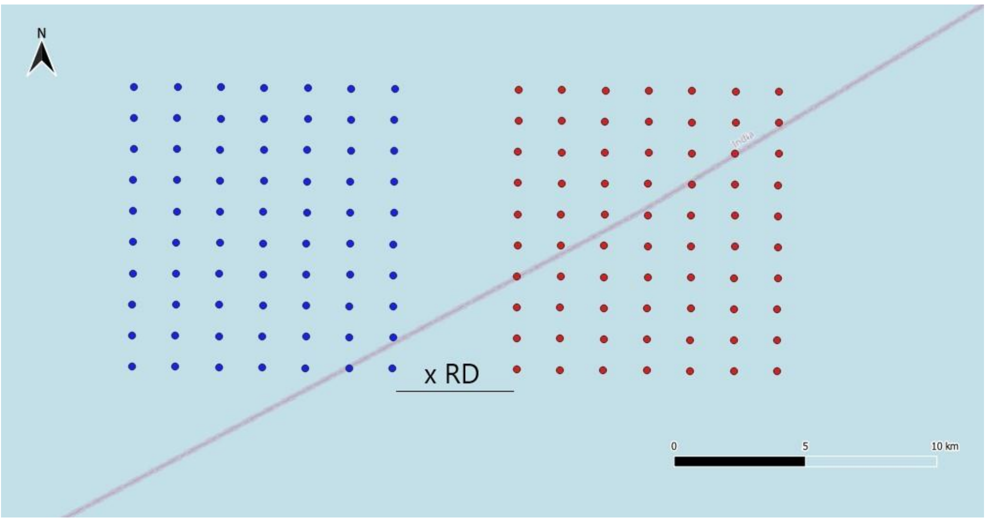


Figure 2.55 - Wind farms configuration

The results of the external wake loss from the western wind farm to the eastern wind farm can be found in Table 2.8. The overall wake loss in the table represents the losses when considering two 1GW neighbouring wind farms (internal + external wakes), while the external wake loss represents the wake increase.

Distance x RD	Distance RD [m]	Overall wake loss [%]	External wake loss [%]
10	2,360	12.8	3.3
15	3,540	12.2	2.6
20	4,720	11.8	2.1
30	7,080	11.2	1.5
40	9,440	10.9	1.2
50	11,800	10.7	0.9

Table 2.8 - External wake loss results depending on spacing between two neighboring wind farms

As expected, the external wake loss from the western wind farm to the eastern wind farm increases as the two wind farms get closer to each other. Even though internal wake is the main contributor to the overall wake loss, the distance between two wind turbine clusters has a significant impact on the external wake loss, varying from 0.9 to 3.3%.

Note that the wake loss calculated with WindPRO can only be considered preliminary, as the real shadow effect can only be demonstrated with CFD tools combined with measurements (e.g., lidar) in an operative scenario. While the used model (i.e., N. O Jensen) is a trusted and widely used in wind flow modelling of wind farms, the result is a guide to the expected wake variance considering clusters of 1 GW.

Nevertheless, scientific analysis using measurement[6] suggests that a wind farm is affected by a up wind neighbouring in the first few rows, and that the modelling and interpretation of experimental results are subject to complications due to factors e.g., wind turbine rotor speeds, inflow conditions across the site and related speed-ups.

[6] *Nicolai Gayle Nygaard and Sidse Damgaard Hansen 2016 J. Phys.: Conf. Ser.* ***753*** *032020*

The same applies to blockage effects, which should be accounted with a loss factor based on published articles (production, 2018).

The assessment of external wake loss provides an understanding on effect and quantum of losses expected to be suffered by other wind farms in the vicinity. The effect is maximum in the direction of the predominant wind, which was the focus of the assessment.

Purely from a wake loss perspective, it would be beneficial to have a large distance (say 50 D or in case of modelled turbine 12.0 Km). However, such a strategy would be detrimental from a societal perspective as this will require large separation distances between the wind farms, implying significantly lower power generation potential for the identified OWF zone in Tamil Nadu.

Clearly, the benefits achieved by maximising 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 of Tamil Nadu. Especially, when it is established that shortlisted OWF site in Tamil Nadu provides the most suitable conditions for OWF development in the country.

There are many international examples of such strategies being adopted. Most recently, Bureau of Ocean Energy Management conducted "New York Bight" auctions for offshore wind farms. The auction areas are illustrated in Figure 2.56, and it can be seen that minimum spacing of 1.0 Nautical miles has been kept between the lease areas.

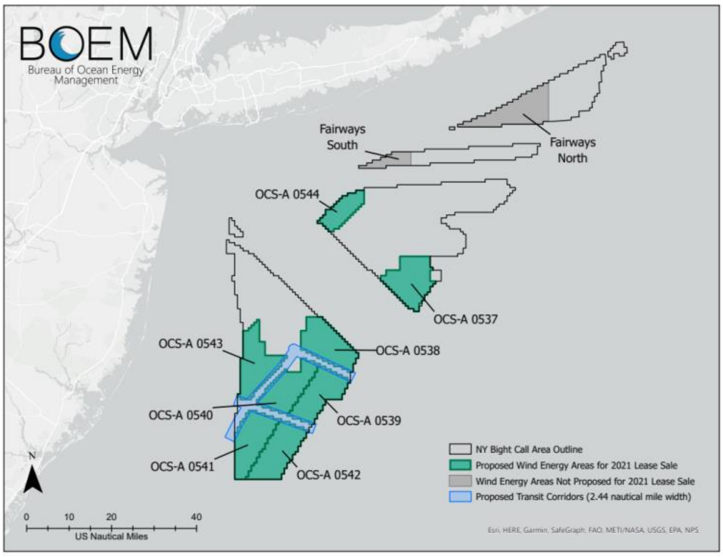


Figure 2.56 - Areas for NY Bight lease auction (Source (BOEM, 2021))

Therefore, it is recommended not to consider the external wake loss effects in the OWF site conceptual planning and separation distance (if any) must only consider practical aspects such as access corridor for construction, installation and operation vessels and electrical export cables.

In terms of accommodating electrical infrastructure there are certain elements to consider, and especially to ensure future possible repair of the electrical cables a rule of thumb is a minimum distance of 2.5 times the water depth pr. cable system (Energinet, 2022). Considering water depths in Tamil Nadu up to 65 meters the minimum distance becomes more than 160 meters.

Looking into other sources the planning principles in Germany (BSH, 2020) is focused on:

- Highest possible bundling in sense of parallel guidance and
- Distance for parallel installation: 100 m; after every second cable system, 200 m

As illustrated in the Spatial Planning Ordinance for the German exclusive economic zone and the below figure there are certain areas designated and reserved for submarine cables in the German part of the North Sea.

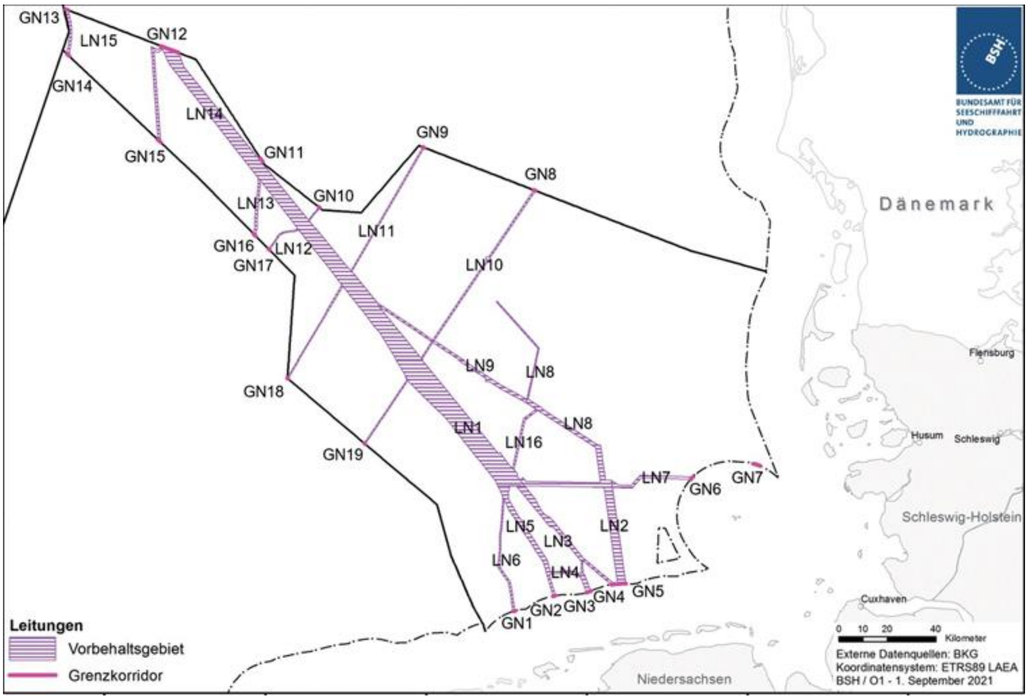


Figure 2.57 – Designations for submarine cables and connection gates in the North Sea (BSH, 2021)

In Germany considering existing cables and approved submarine cables the site development plan considers regularly maintaining 500 m unless subsoil condition require greater distances (BSH, 2019).

In terms of cable protection, the distance applied in Denmark is 200 m (Danish order, 1992) in Danish legislation and the order on protection of submarine cables and pipelines.

In Belgium the technical and spatial planning criteria is specified as cables must be routes in the designated cable corridors identified in the marine plan, and there has to be a minimum of 250 meters of free space on either side of the cable or pipeline (The NorthSEE project, 2019).

Similar distances are considered in the Netherlands with a maintenance zone of 500 meters around cables and pipelines in the North Sea, and sand may not be extracted within this zone. Research has shown that in principle, when building wind farms, a 500-metre zone should be adhered to for pipelines and electricity cables and a 750-metre zone for telecommunications cables. With a view to efficient use of space, maintenance zones for cables and pipelines can be reduced where possible. To ensure efficient use of space, efforts are also being made to bundle cables and pipelines in consultation with the initiator, to downsize maintenance zones wherever possible (Netherlands' MSP, 2015).

2.3.7 Summary

The site screening process identified (discussed in section 2.2 and section 2.3) and have evaluated the key constraints and potential conflicts with competing users that offshore wind farm development in Tamil Nadu zones B, G, E and D may present. Based on preliminary evaluations of these potential conflicts, a shortlisted site area (~ 3600 km²) is identified for priority development of offshore wind farms in Tamil Nadu.

The key factors that have influenced the determination of shortlisted site within Zones B, G, E and D are listed as follows:

- **Wind Resource**: the zones are amongst the best available areas in the country having excellent wind conditions ranging from 7.0 m/s to slightly above 10.5 m/s at 150 m hub height.

- **Bathymetry**: depth to the seabed ranges from 10-65 m, which is suitable for the deployment of fixed foundation offshore wind turbines. However, gaps in the publicly available data exists in terms of geotechnical / geo physical to allow further fine screening / assessment of site suitability.

- **Marine traffic consideration**: a significant portion potential area within Zone G and E are excluded from considerations due to conflict with international shipping lane.

- **Environmental and social considerations**: all of the area within the shortlisted site are at a considerable distance from the identified environmental exclusion zones, and the various social constraint besides marine traffic is considered limited with the current information available. With this being the first maritime spatial planning exercise, it is important to emphasise the importance of future engagement with the various relevant stakeholders as specified earlier and also continuously develop and expand the data gathering.

2.4 Results

2.4.1 Conceptual plan and build-out considerations

This section presents the conceptual plan for proposed sites within Tamil Nadu 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
- 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

The conceptual plan option presented in the previous section and in appendix C consider approaches for management of marine traffic currently passing through, as well as to the south of the proposed sites to accommodate an international shipping route.

At present, we are not aware of any marine traffic separation scheme is being implemented in India. Therefore, it is important to liaise with the relevant government authorities, such as Ministry of Ports, Shipping and Waterways (MoPSAW) to obtain their feedback as well as request them to discuss the potential process of preparing a TSS around the Tamil Nadu site if required. A significant portion of these zones lies within the extended economic zone and outside the territorial water of India. International Navigation has received extensive protection under United Nation Laws of the Sea (UNCLOS), and the design / finalisation of such a TSS is expected to require closer cooperation and acceptance by the International Maritime Organisation (IMO).

Therefore, the engagement and dialogue will not only include MoPSAW and Tuticorin Port authorities on design and implementation of a Traffic Separation Scheme but also liaison with the IMO to ensure further alignment and preparation of Maritime Spatial Plans for the proposed sites to allow strong utilisation of wind potential as well as minimisation of navigational risks.

The approach taken with the currently available data is to draw the developable offshore wind zone borders with high intensity marine traffic area in the Northwest – Southeast direction to offshore wind development zones of G and E. There is no extra safe distance being provided as a risk mitigation measure because the width of the observed marine traffic is 50 km and is wide enough to allow space for vessels to manoeuvre. It should be noted though that most of the marine traffic is caused by international commercial vessels as explained in section 2.3.1 which might prevent the creation of alternative shipping routes, but further navigational risk assessments including various collision risk assessments needs to be carried out before the actual deployment of turbines.

2.4.1.2 Energy Density and area requirements

The energy density adopted in the conceptual planning influences the overall power generation from any offshore wind areas. Tamil Nadu zones considered in the study are the most suitable sites for offshore wind development considering wind resource availability and other physical considerations.

Accordingly, it would be beneficial (and somewhat necessary) to adopt a higher build-out rate at these sites to attain the National vision of 30 GW by 2030. The rough and fine screening exercise and the conceptual planning analysis illustrates the importance of ensuring an optimal utilisation of this valuable area south of Tamil Nadu.

Given the lack of any surveys and investigations carried out including especially geophysical and geotechnical information, 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 Stakeholders, 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.

2.4.1.3 Module size

Currently in the market we experience OSS sizes in the range of 500-750 MW as this is a well-developed and proven design, but we 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 favour 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 matured and experienced.

2.4.1.4 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 a 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 the identified OWF zone in Tamil Nadu.

As previously specified, the benefits achieved by maximising 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 of Tamil Nadu. Especially, when it is established that the proposed OWF site in Tamil Nadu provides the most suitable conditions for OWF development in the country.

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.

In terms of electrical infrastructure corridors these are oriented towards the coastline for the shortest distance to the coastline, and these corridors can also provide ease of access to the construction and operational vessels.

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 mentioned above, it is considered that a corridor width of 1 km between the sites will be sufficient 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 optimisation 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.

2.4.1.5 Grid connection points and electrical configuration

The below three (3) substations appears to be promising for potential connection to the wind farms in the vicinity of the most attractive zones in Tamil Nadu:

- Sanganeri Substation (230 KV)
- Udayathur Substation (230 KV)
- Koodankulam Substation (400 KV)

All the above substations are located within 20 km from the boundary of the zone B. While 230 KV substations are acceptable for early phase / demonstration project (say 500 -700 MW), connections to 400 KV substations would be required for larger scale development of offshore wind zones.

The closest 400 KV substation is Koodankulam substation, which is currently connected to Koodankulam Nuclear Power Plant. This Power Plant is expected to have significant balance capacities for upgrade given the expansion plans of this Nuclear Power complex, but all of the above needs to be assessed and qualified.

It is very important to emphasise the importance of ensuring optimal planning of the transmission and grid infrastructure and close collaboration between the relevant stakeholders. The developments to ensure the evacuation of the offshore wind power and potential reinforcement required can have a long lead time, and therefore proactive planning is needed to ensure timely delivery.

2.4.2 Proposed build-out plan

Based on the above considerations the initial proposed build-out plan focuses initially on the most attractive sites closest to the coast, and in terms of size an approximate area requirement of 200 km^2 could support capacities of approx. 1 GW, though this is very dependent on the potential constraints and risks, which are unknown due to the lack of site investigations and surveys carried out to provide the relevant insight. As pr. the MNRE strategy paper (July 2022) the indicative auction trajectory for offshore wind is as listed below:

Year	Total auction trajectory (GW)
2022-23	4[7]
2023-24	4[8]
2024-25	4
2025-26	5
2026-27	5
2027-28	5
2028-29	5
2029-30	5
Total	**37**

Table 2.9 - Total Auction Trajectory in GW

Figure 2.58 illustrates the buildout of the areas that are assessed to be most suitable for offshore wind development after taking into consideration the assessments made during rough screening, fine screening, the heat mapping, and conceptual planning.

[7] The whole capacity is planned to be allocated to sites in Tamil Nadu
[8] 1 GW of this capacity is planned to be allocated to a site in Gujarat

The red lines represent the offshore wind zones G, B, E and D that show the highest potential for initial development. The sites, which are closer to shore, are divided into similar size of around 200 km^2 to accommodate for an approximate capacity of 1 GW as mentioned above and are represented with black lines as site borders. The second row of sites from the shore are divided into relatively larger sizes in order to be able to compensate for longer distance to shore, higher water depth and lower economic ranking. There is also the possibility to develop higher capacities in these areas. Having larger site area will enable more space for optimization and will increase the competitiveness in comparison to the sites closer to shore considering the uncertainty about the site conditions. As stated in section 2.4.1.4 , a corridor width of 1 km is allocated as an initial planning assumption between the sites for safe operations as well as export cable corridors.

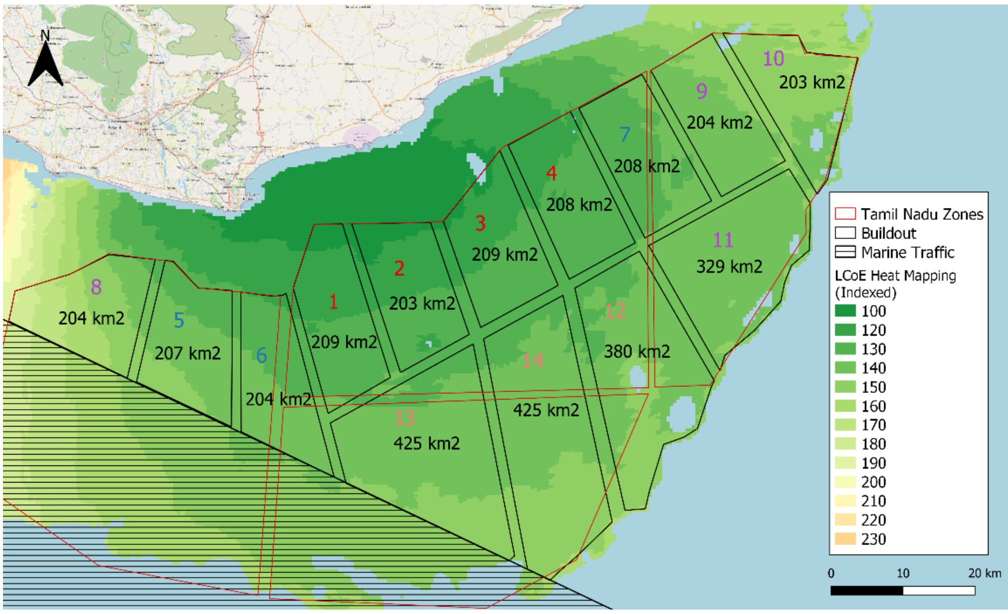


Figure 2.58 - Buildout Plan for Tamil Nadu

The potential capacities of the sites with densities ranging from 3.0 MW/km^2 to 7.0 MW/km^2 can be seen in Table 2.10 below:

Site #	Area (Km²)	Densities		
		3.0 MW/km²	5.0 MW/Km²	7.0 MW/Km²
		Capacities (MW)		
1	209	627	1045	1463
2	203	609	1015	1421
3	209	627	1045	1463
4	208	624	1040	1456
5	207	621	1035	1449
6	204	612	1020	1428
7	208	624	1040	1456

8	204	612	1020	1428
9	204	612	1020	1428
10	203	609	1015	1421
11	329	987	1645	2303
12	380	1140	1900	2660
13	425	1275	2125	2975
14	425	1275	2125	2975
Total	**3618**	**10854**	**18090**	**25326**

Table 2.10 - Area and capacity of selected sites for buildout plan

The site numbers illustrated in Figure 2.58 matches with the site numbers in first column of Table 2.10. The coordinates of each individual site can be seen below in Table 2.11 with each row representing the corner points of the site polygon. The coordinates are represented in degrees, minutes and seconds in the projected coordinate system WGS 72BE UTM zone 44N.

Site #	Lat	Long
1	07° 58' 55.18210279" N	077° 37' 12.02065596" E
1	08° 03' 43.86189371" N	077° 38' 44.11998271" E
1	08° 03' 47.08469163" N	077° 40' 52.99759552" E
1	07° 52' 13.83103455" N	077° 44' 37.29375890" E
1	07° 49' 28.65104409" N	077° 39' 55.45169623" E
1	07° 58' 55.18210279" N	077° 37' 12.02065596" E
2	08° 03' 47.72371698" N	077° 41' 35.96290002" E
2	08° 03' 57.00346702" N	077° 47' 33.44613731" E
2	07° 55' 30.88471532" N	077° 50' 33.38988611" E
2	07° 52' 36.82018998" N	077° 45' 22.52165955" E
2	08° 03' 47.72371698" N	077° 41' 35.96290002" E
3	08° 04' 02.28905987" N	077° 48' 31.78896036" E
3	08° 09' 24.80536546" N	077° 52' 46.05191377" E
3	07° 59' 16.22684932" N	077° 57' 15.96460351" E
3	07° 56' 03.13526471" N	077° 51' 25.35945949" E
3	08° 04' 02.28905987" N	077° 48' 31.78896036" E
4	08° 09' 49.11076938" N	077° 53' 23.24046568" E
4	08° 12' 24.25027828" N	077° 58' 05.34119981" E
4	08° 02' 31.37124854" N	078° 03' 04.96530421" E
4	07° 59' 44.48055006" N	077° 58' 06.18390086" E
4	08° 09' 49.11076938" N	077° 53' 23.24046568" E
5	08° 00' 54.28839758" N	077° 27' 28.85848997" E
5	08° 00' 51.98256744" N	077° 28' 05.21346003" E
5	07° 58' 52.04896032" N	077° 29' 59.87801480" E
5	07° 58' 40.63219616" N	077° 32' 35.74430290" E
5	07° 48' 24.59450207" N	077° 32' 37.03942199" E
5	07° 51' 44.61656638" N	077° 25' 23.96926039" E
5	08° 00' 54.28839758" N	077° 27' 28.85848997" E
6	07° 58' 34.68200788" N	077° 33' 14.61680538" E
6	07° 58' 17.20337524" N	077° 35' 41.67334128" E
6	07° 58' 21.81288230" N	077° 36' 24.53319668" E
6	07° 58' 31.30960553" N	077° 36' 39.64314789" E
6	07° 44' 41.47105107" N	077° 40' 24.82125405" E
6	07° 48' 02.20013345" N	077° 33' 21.42063696" E
6	07° 58' 34.68200788" N	077° 33' 14.61680538" E
7	08° 12' 37.91193679" N	077° 58' 43.82592826" E
7	08° 15' 13.82133421" N	078° 03' 29.58241167" E
7	08° 05' 44.39836787" N	078° 08' 50.79919045" E

7	08° 02' 53.41435470" N	078° 03' 48.41315508" E
7	08° 12' 37.91193679" N	077° 58' 43.82592826" E
8	07° 58' 30.33143998" N	077° 16' 09.04137618" E
8	07° 59' 48.90680417" N	077° 20' 17.27000005" E
8	08° 01' 18.75414078" N	077° 23' 13.62068673" E
8	08° 00' 59.11329808" N	077° 26' 44.47382096" E
8	07° 52' 01.20573916" N	077° 24' 41.79192222" E
8	07° 56' 14.08341944" N	077° 15' 41.55617817" E
8	07° 58' 30.33143998" N	077° 16' 09.04137618" E
9	08° 15' 32.11071367" N	078° 04' 09.70559677" E
9	08° 18' 19.61987184" N	078° 08' 46.46421194" E
9	08° 08' 47.45387218" N	078° 14' 24.36867201" E
9	08° 06' 03.12614358" N	078° 09' 34.83845947" E
9	08° 15' 32.11071367" N	078° 04' 09.70559677" E
10	08° 18' 23.15699062" N	078° 09' 35.96920951" E
10	08° 18' 14.42777667" N	078° 15' 19.56389762" E
10	08° 16' 58.29950502" N	078° 15' 58.43976767" E
10	08° 16' 35.99457199" N	078° 19' 50.27896696" E
10	08° 07' 24.39370128" N	078° 17' 36.59823722" E
10	08° 06' 17.24001953" N	078° 16' 50.73123357" E
10	08° 18' 23.15699062" N	078° 09' 35.96920951" E
11	08° 08' 11.29589253" N	078° 14' 41.63988006" E
11	08° 05' 35.73940718" N	078° 16' 19.33342989" E
11	08° 04' 57.98614800" N	078° 16' 19.91835497" E
11	08° 02' 04.14643594" N	078° 16' 16.18655536" E
11	08° 00' 54.11863666" N	078° 14' 55.90246981" E
11	07° 59' 37.46750361" N	078° 14' 24.96798289" E
11	07° 58' 11.41121293" N	078° 14' 07.99840949" E
11	07° 55' 58.77516874" N	078° 12' 09.19398588" E
11	07° 54' 03.97912806" N	078° 09' 55.16064656" E
11	07° 52' 54.98392620" N	078° 09' 34.27230090" E
11	08° 02' 19.25746235" N	078° 04' 06.08348106" E
11	08° 08' 11.29589253" N	078° 14' 41.63988006" E
12	08° 01' 53.69961989" N	078° 03' 23.51782678" E
12	07° 52' 09.77104527" N	078° 09' 08.42430667" E
12	07° 51' 43.20657021" N	078° 08' 55.42343941" E
12	07° 48' 32.77760265" N	078° 07' 53.47208800" E
12	07° 47' 53.58829271" N	078° 06' 53.14223854" E
12	07° 47' 19.73490903" N	078° 05' 19.93768282" E
12	07° 43' 51.63507155" N	078° 04' 17.89437024" E
12	07° 42' 27.68109495" N	078° 03' 58.87786307" E
12	07° 42' 20.21797023" N	078° 02' 26.82989813" E
12	07° 59' 04.36545731" N	077° 58' 31.70175866" E
12	08° 01' 53.69961989" N	078° 03' 23.51782678" E
13	07° 48' 45.60025502" N	077° 40' 05.49019943" E
13	07° 54' 48.57062926" N	077° 50' 51.74206470" E
13	07° 38' 50.89710540" N	077° 54' 06.93520381" E
13	07° 38' 42.17315576" N	077° 53' 56.34085329" E
13	07° 38' 30.09624334" N	077° 53' 44.04326774" E
13	07° 38' 30.06784593" N	077° 53' 38.24126067" E
13	07° 44' 12.95618121" N	077° 41' 19.38420765" E
13	07° 48' 45.60025502" N	077° 40' 05.49019943" E
14	07° 55' 11.79361368" N	077° 51' 38.92752112" E
14	07° 58' 31.56061750" N	077° 57' 38.18124271" E
14	07° 41' 26.83772139" N	078° 01' 29.03317188" E

14	07° 40' 25.46633473" N	078° 00' 25.86779902" E
14	07° 39' 03.21925376" N	077° 59' 02.82007333" E
14	07° 38' 59.70350976" N	077° 58' 59.47243427" E
14	07° 38' 56.08406121" N	077° 58' 55.69638254" E
14	07° 37' 30.77144500" N	077° 57' 18.49450152" E
14	07° 37' 00.78265983" N	077° 56' 47.66308208" E
14	07° 37' 49.90206152" N	077° 55' 05.94017387" E
14	07° 55' 11.79361368" N	077° 51' 38.92752112" E

Table 2.11 – Coordinates of selected sites for buildout plan

Considering an initial capacity of 4 GW, it would make sense to start the first auctions of 4 GW capacity in 2022-2023 with sites 1, 2, 3 and 4. These are the most attractive sites both from the perspective of LCoE illustrated by the heat mapping and the assessed constraints. As also illustrated by the heat mapping the 4 proposed sites are very comparable (from an LCoE perspective on par), which obviously supports competition between the sites. In the case where the sites are far from comparable, it is more likely to see bids being less close to the marginal costs and more speculative bids. A closer look at the first four recommended sites can be seen below in Figure 2.59.

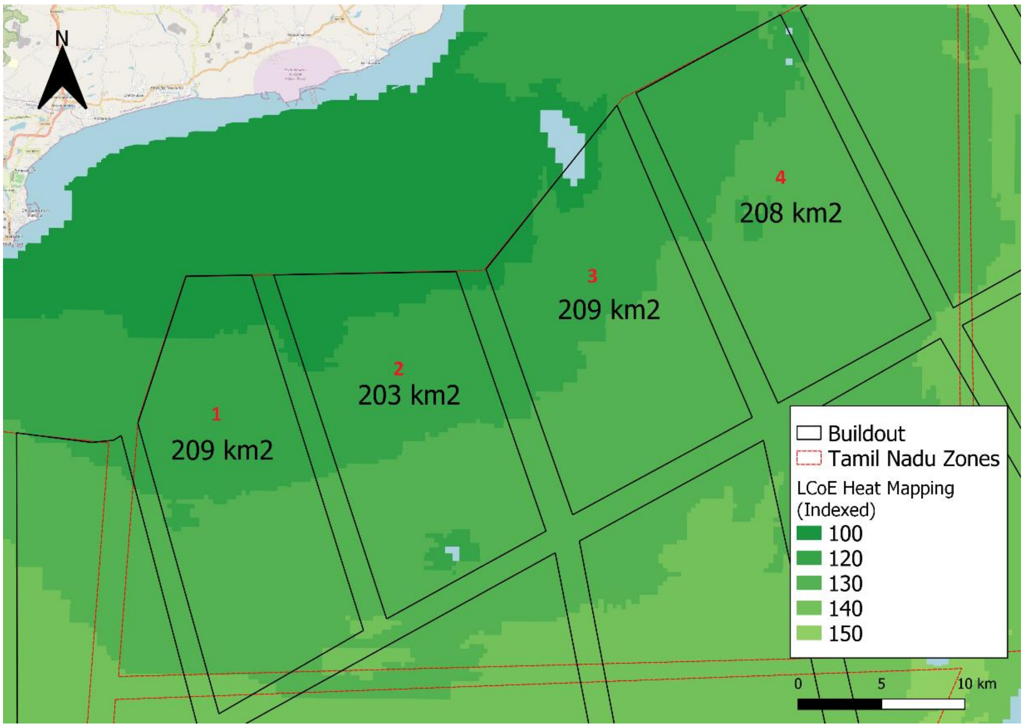


Figure 2.59- Most attractive site areas in Tamil Nadu

With a potential phased approach following the indicative auction trajectory time the option of evaluation could be considered. Time and development of the initial sites will also provide insights to the further development within the zones south of Tamil Nadu and extending the wind farm sites further to the borders and closer to the potential constraints to the south-west (marine traffic) and north-east (environmental sensitive areas) is proposed in a potential second phase if this makes sense.

To create enough competition more sites (and GWs) than the target could also be allocated to make sure that there are enough matured sites to participate in each future auction round. With the ambition and trajectory from the government of initially procuring 4 GW of power, there could also be an initial auction of around 10 GW or more of leases awarded e.g., this could be the 10 first sites illustrated in the table above. This would also allow for future procurement of capacity beyond 4 GW and more parallel development of sites.

As mentioned, the 30 GW target set and 37 GW indicative auction trajectory represents a future pipeline and this volume and scale together with the technological development also supports the gradual increase in windfarm size as indicated above for the sites later in the pipeline.

2.4.3 Future perspectives and next steps

2.4.3.1 International Financing Criteria

Offshore wind is a clean and reliable source of energy that has significant potential to decarbonize the power sector and thereby the consumers of energy production. However, they are also capital-intensive projects, requiring significant investment in project development as well as enabling infrastructure (such as grid improvements and power offtake infrastructure, supply chain improvements, etc.). Therefore, it is considered important that the offshore wind industry in India has access to various international financing instruments that would allow large capital investment inflows in offshore wind development.

The Equator Principles (Association, July 2020) are adopted by approximately 123 key financial institutions covering majority of international project finance debt within developed and emerging markets. They are essentially the tools that assist international financial institutions in determining and managing environmental and social risk in financing. These standards are primarily based on the IFC Performance Standards on social and environmental sustainability and on the World Bank Group Environmental, Health, and Safety Guidelines, which consists of 10 environmental and social standards (ESS) as follows:

- **ESS 1:** Assessment and management of Environmental and Social Risks
  and impacts
- **ESS2:** Labour and working conditions
- **ESS3:** Resource Efficiency and Pollution Prevention and Management
- **ESS4:** Community Health and Safety
- **ESS5:** Land Acquisition, Restriction and Land use and involuntary Resettlement
- **ESS6:** Biodiversity conversation and sustainable management of living natural resources
- **ESS7:** Indigenous Peoples / Sub – Saharan African underserved traditional
  local community
- **ESS8:** Cultural Heritage
- **ESS9:** Financial Intermediaries

- **ESS10:** Stakeholder Engagement and Information Disclosure

Offshore wind farms by its nature have potential to significantly impact the marine ecology, if they are not carefully planned and constructed adopting good environmental practices. Internationally, in accordance with Equator Principles, such impacts are avoided by carefully selecting the sites and avoiding areas known to support diverse marine habitats. In most geographies, such habitats are identified and designated, where relevant, as Marine Protected Area (MPAs), Key Biodiversity Areas (KBAs), National Parks (NPs), Nature Reserves, Ramsar sites and locally protected wetlands and World Heritage Sites. These protected areas are usually not considered for offshore windfarms development unless sustainable solutions for coexistence can be obtained. Further, there are several important natural marine habitats that are sensitive to impacts. These habitats include coral reefs, seagrass beds, mangroves, and nearshore flats. They also provide feeding grounds to resident and migratory bird species. Most of such sensitive habitats occur in shallow coastal waters and are therefore vulnerable to nearshore project development.

As such, the MSP for Tamil Nadu sites considers a varying separation distance ranging from less than 10 km to 20 km from the shoreline as can be seen in Figure 2.60. It can be observed that zones G, B, D and A have zone borders starting 10 km away from the shoreline whereas zone C has closest borders 20 km away from the shoreline. Zone F, which is the least feasible zone for offshore wind development with fixed-bottom turbines, has borders very close to shore while most of the zone area falling at least 20 km away from shore. According to Danish best practices, a minimum distance of 15 km is given as site borders to shoreline in order to avoid any potential conflicts with nearshore environmental and social sensitive receptors. During the fine screening process, the environmental exclusion zones (Marine Protected Area (MPAs), Key Biodiversity Areas (KBAs), National Parks (NPs), Nature Reserves, Ramsar and locally protected wetlands and World Heritage Sites) from the site planning (based on publicly available data sets) have been excluded from the development zones. However, the environmental data availability is still very limited and therefore robust environmental assessment, based on long-term site-specific survey observations are necessary for a comprehensive assessment of environmental impact of OWF development on the environment. Therefore, a minimum distance of 15 km from the shore hasn’t been considered as a hard constraint for the MSP.

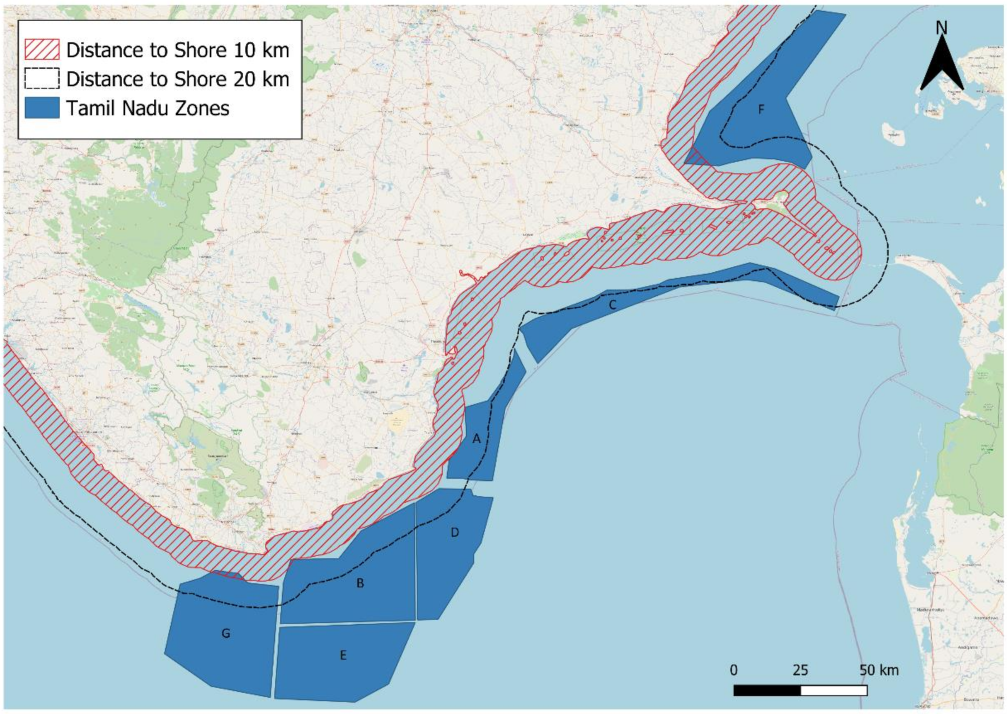


Figure 2.60 - Distance to shore from offshore wind zones

Onshore wind farms in India, are currently excluded from the requirement of environmental assessment and do not require obtaining environmental consent from Ministry of Environment, Forest and Climate Change (MOEF&CC). However the requirements under Costal Regulatory Zones (CRZ) shall apply to offshore wind farm projects.

Internationally, developers are required to prepare an ESIA (Environmental and Social Impact Assessment) for approval by regulatory authorities for all offshore wind projects.

It is therefore, advantageous to apply environmental standards consistent with international standards and aligned with the Equator Principles to the offshore wind development to protect, sustain and potentially improve the environment. This is also necessary to make the offshore wind industry attractive to international investors and financial institutions. To support the above, it is important to assess the need for institutional strengthening to ensure that such international environmental standards will be applied in case of planned OWF in Tamil Nadu and elsewhere.

2.4.3.2 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 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 times 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 the marine spatial planning outcome, it is imperative that seabed conditions are assessed thoroughly, key geotechnical risks 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. Accordingly, we recommend that further geophysical and geotechnical data sets be obtained for the study area. In this relation, it is noted that Geological Survey of India (GSI) has conducted geological research within the areas south of Tamil Nadu coastline (Refer Figure 2.61). Accordingly, GSI was approached requesting access to the geophysical data in relation to survey areas SR –006. This data will be very valuable to further evaluate the sites and get insight to the risks related to the seabed conditions.

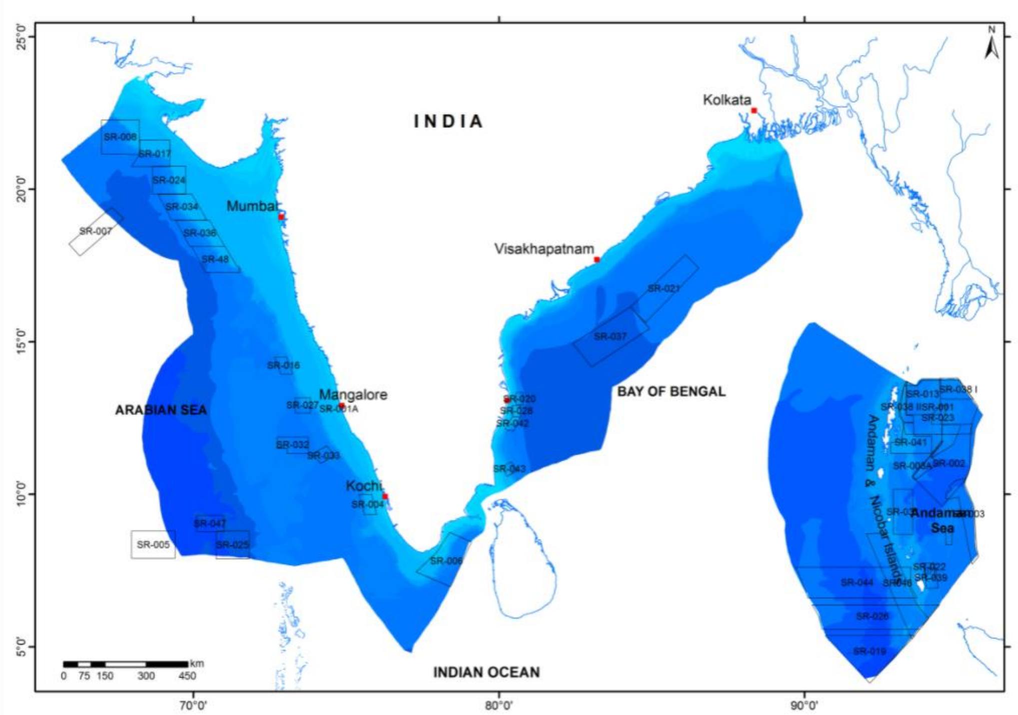


Figure 2.61 - Survey areas of Geological Survey of India (Ratnakar, 2014)

2.4.3.3 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 plans. Addressing spatial conflicts is considered as key to 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 Tamil Nadu:

- 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 separation schemes.

- Transmission Grid and electrical system: The available information in the public domain only allows for a high-level screening of available grid connections and rated capacities of potential point of interconnection (substations). It is therefore essential to have a close liaison with Transmission System Operators (PowerGrid and TRANGEDCO) 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 Tamil Nadu) and other environmental institutions are consulted to further understand/ evaluate potential conflicts and concerns.

- Fisheries: The analysis established that the area off the coast of Tamil Nadu is one of the most frequented areas by local fishermen. 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 (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 Tamil Nadu, 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.

- Oil and gas activities: Currently there are no existing blocks that are open for lease for oil & gas exploration in the OWF zones. According to the feedback received from Directorate General of Hydrocarbons (DGH) in November 2022, coexistence of oil & gas and offshore wind is possible in the region. Therefore, it will be beneficial to maintain constant communication, which is already in motion between DGH and MNRE.

In the appendix E an overview of the engagement with the various Indian stakeholders is presented, and as mentioned 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 2.62, there is representation at the political level with ministries and at the operational level with the various agencies.

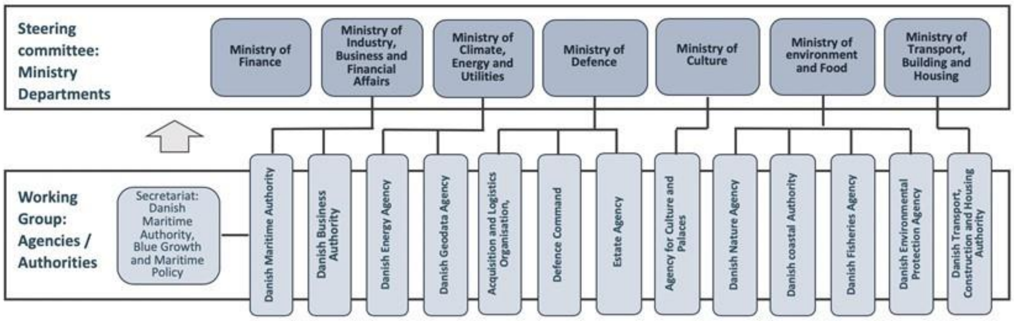


Figure 2.62 - Governance structure for MSP

Similarly, a proposed Indian maritime spatial planning committee could be established consisting of various institutional stakeholders to ensure 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 2.63.

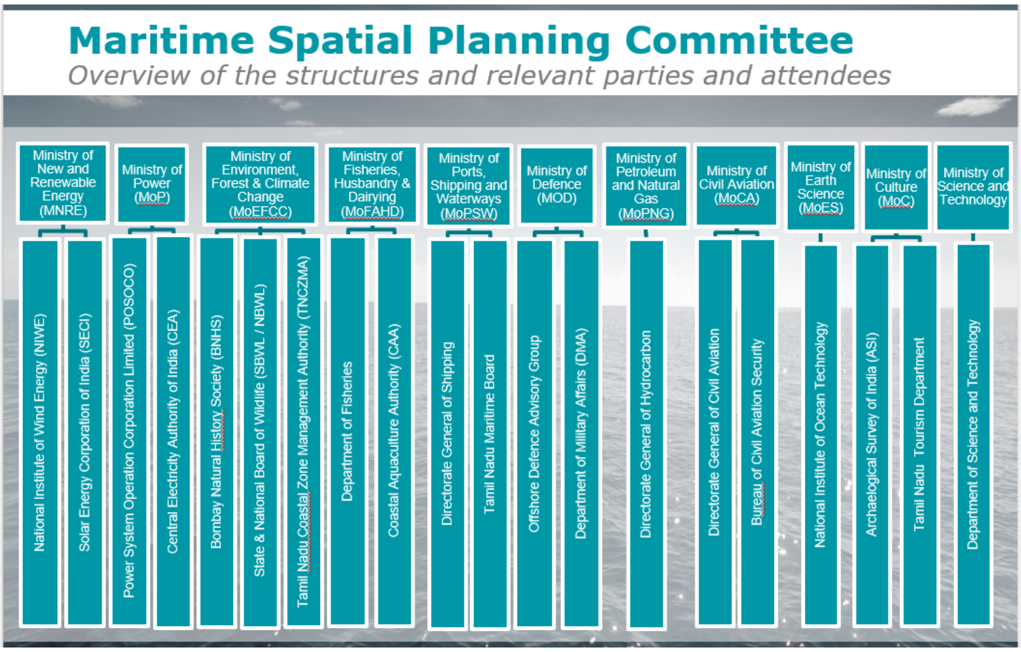


Figure 2.63 – Proposed Maritime Spatial Planning Committee

References

AAI. (2021). https://nocas2.aai.aero/nocas/CCZMPage.html) .

AAI. (2022). https://nocas2.aai.aero/nocas/CCZMPage.html).

arXiv:1909:13780. (n.d.). *A parmetric model for wind turbine power curves incoprporating environmental conditions.*

Association, T. E. (July 2020). *The-Equator-Principles.* The Equator Principles Association.

Badrinarayanan, S. S. (2003). *New Archaelogical Sites in Gulf of Cambay, India , : National Institue of Ocean Technology .* Chennai .

Baltic LINes. (2018). *Capacity Densities of European Offshore Wind Farms.*

BMTPC. (2021). *Wind and Cyclone Hazard Map of India.* https://www.bmtpc.org/DataFiles/CMS/file/map%20of%20india/wind-india.pdf.

BOEM. (2021). *New Your Bight Lease Auctions .* https://www.boem.gov/renewable-energy/state-activities/new-york-activities.

BSH. (2020). *Flächenentwicklungsplan 2020 für die deutsche Nord- und Ostsee.* Hamburg and Rostock: BSH.

BSH. (2021, 11 26). *Annex to the Spatial Planning Ordinance for the German exclusive economic zone in the North Sea and in the Baltic Sea.* Federal Law Gazette.

BVG Associates. (2014). *UK offshore wind supply chain: capabilities and opportunities.*

Cooray, P. a. (1991). *Geological evolution of the coastal zone of Sri Lanka.* Seminar on causes of coastal erosins in Sri Lanka organized by CCD/GTZ coast conservation project.

COWI. (2019). *Havvindmøllepark Vesterhav Syd: Sejladsrisikovurdering.*

COWI. (2020). *Input to roadmap for offshore wind development in Vietnam.* Danish Energy Agency.

COWI. (2021).

COWI. (2022).

COWI. (2022).

DEA. (2019). *Havvindspotentialet i Danmark - screening af de danske farvande for mulige placeringer til ny havvind.* Danish Energy Agency.

Department of Environment and Climate Change, Government of Tamil Nadu. (2017). *State of Environment Report for Tamil Nadu.* Retrieved from https://www.environment.tn.gov.in/template/ngc-reports/soer1.pdf

Department of Fisheries and Fishermen Welfare, Government of Tamil Nadu. (n.d.). *Fisheries at a Glance 2020-2021.* Retrieved from https://www.fisheries.tn.gov.in/includes/assets/cms_uploads/pdf/glance/Fisheries_at_a_glance_2020-21__Marine_9988.pdf

DGH. (2021). *Indian Sedimentray Basins.* Directorate General of Hydrocarbons (Ministry of Petroluem & natural Gas).

DGH. (2021). *Maps of active (all) and relinquished offshore blocks.* Directorate General of Hydrocarbons.

DGH. (2022). *Indian Sedimentray Basins.* Directorate General of Hydrocarbons (Ministry of Petroluem & natural Gas).

DNV. (2015). *Kriegers Flak Havmøllepark: Sejladsforhold - VVM-redegørelse - Teknisk baggrundsrapport.*

ECN. (2018). *Optimal wind farm power density analysis for future offshore wind farms.*

EDX. (2021). *Global Oil and Gas Features Database.* Energy Data Exchange.

EDX. (2022). *Global Oil and Gas Features Database.* Energy Data Exchange.

EMODnet. (2021). *Bathymetry.* https://emodnet.ec.europa.eu/en.

Esberg, P. o. (n.d.).

ESMAP. (2021). *Global Wind Atlas .* https://globalwindatlas.info/.

ESMAP. (2022). *Global Wind Atlas.* https://globalwindatlas.info/.

ESRI. (2020). *World seafloor geomorphology.* https://www.arcgis.com/home/item.html?id=3a40d6b0035d4f968f2621611a77fe64.

Esvagt. (n.d.). *Service Operation Vessels for Offshore Wind*. Retrieved 10 26, 2019, from https://www.esvagt.com/wind/

Forum, M. (2021). *Call for proposals-projects on MAritime Spatial Planning (MSP).* Maritime Forum europa.eu.

FOWIND. (2015). *Feasibility Study for Offshore Windfarm Development in Tamil Nadu,188 pp.* FOWIND.

Ganapathy, G. (2010). A deterministic seismic hazrad anaylysis for major cultural heritage sites of Tamil Nadu,India. *International Journal fo Geomatics and geosciences,Vol 1,.no.3*.

GOV.UK. (n.d.). *Marineservices*. Retrieved August 18, 2021, from Explore marine plans: https://explore-marine-plans.marineservices.org.uk/

GSI. (2006). *Geology and mineral resources of the states of India,Chennai.* Geological Survey of India.

IMF. (2021). *Global Shipping traffic density.* World Bank and IMF.

IMF. (2022). *Global Shipping traffic density.* World Bank and IMF.

India Meteorological Department, Chennai. (2008). *Electronic Atlas of Tracks of Cyclones and Depressions in the Bay of Bengal and the.*

International Renewable Energy Agency (IRENA). (2018). *Renewable Energy Benefits - Leveraging Local Capacity for Offshore Wind.*

Jan De Nul Group. (n.d.). *Offshore Jack Up Installation Vessel*. Retrieved 10 26, 2019, from https://www.jandenul.com/en/wind-turbine-installation-vessel

Jan De NUl Group, u. (n.d.). *Concept/system sub report.* Jan De NUl Group,u.d.

LEANWIND. (2015). *Ports suitability assessment for offshore wind development. Case Studies Report.*

Maritime and Coastguard Authority. (2008). *MGN 317: Offshore renewable energy installations (OREIs) - Guidance on UK navigational practice, safety and emergency respone issues.*

MEASNET. (2016). *Evaluation of site specifioc wind conditions,version 2.* MEASNET.

Menon, A. a. (2010). Probabilistic Seismic Hazard Macrozonation of Tamil Nadu in Southern India. *Bulletein of the Seismological Society of America,vol.100*, pp. pp1320-1341.

Ministry of Transport for the Netherlands. (2013). Annex A: Netherlands summary of international regulations and guidelines for marine spatial planning related to safe distances to multiple offshore structures (e.g. wind farms). In World Ocean Council and The Nautical Institute, *The Shipping Industry and Marine Spatial Planning.*

NGRI. (1978). *Gravity map series of India (1:5000000),First edition, explanotory note.* National Geophysical Research Institute ,India.

NREL. (n.d.). *NREL Market Report Finds U.S. Offshore Wind Industry Poised for Multigigawatt Surge*. Retrieved 10 22, 2019, from https://www.nrel.gov/news/program/2017/nrel-market-report-finds-us-offshore-wind-industry-poised-multigigawatt-surge.html

ONGC. (1993). *Composite Bouguer Gravity Map of Cauvery basin,Tamil Nadu.* Oil and Natural Gas Corporation Limited.

PRDS. (2021). *Background on PSDS data to COWI.* The Petroleum Resources Development Secretariat.

production, W. b. (2018, June). Windfarm blockage amd the consequences of neglecting its impact on enrgy production.

Ratnakar, R. S. (2014). gsi.gov.in.

Ratnakyake, A. a. (2017). Assessment of hydrocarbon generation potential and thermal maturity of the offshore Mannar Basin ,Sri Lanka. *Jaournal of Petroluem exploration and production technology*.

Robak, S., & Raczkowski, R. (2018). *Bulletin of the Polish Academy of Natural Sciences Technical Sciences, 66*(4), 517-528.

S.K, W. (2016). *Marine geololgy and coastal surveys for seabed mapping and mineral resource evaluation in India-An overview.* Proc Indian Natn Sci Acad 82 No.3 July Spl issue,pp.675-83.

Saravanavel, J. S. (2020). GIS based 3D visualiazation of subsurface geology and mapping of probable hydrocarbon locales,part of Cauvery basin,India. *Journal of Earth system Science 129:36*, 12 pp.

Tchakoua, P., Wamkeue, R., & Theubou, T. (2013). A review of concepts and methods for wind turbines condition monitoring. *2013 World Congress on Computer and Information Technology.*

TeleGeography. (2021). *Submarine Cable map.* https://www.submarinecablemap.com/country/india).

TeleGeography. (2022). *Submarine Cable map.* https://www.submarinecablemap.com/country/india).

The Crown Estate. (2021, June 30). *Offshore Wind*. Retrieved from https://www.thecrownestate.co.uk/round-4/

Wadhawan, S. (2016). *Marine Geology and Coastal Surveys for seabed mapping and mineral resource evaluation in India - An OVerview .* Proc Indian Natn Sci Acad 82 No 2 .

World Bank. (2021). *Offshore Wind Roadmap for Vietnam.* Washington, DC: World Bank.

Appendix

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

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

Appendix C. Technical Note on Marine Traffic Systems in Tamil Nadu

Appendix D. Technical Note on Electrical Systems in Tamil Nadu

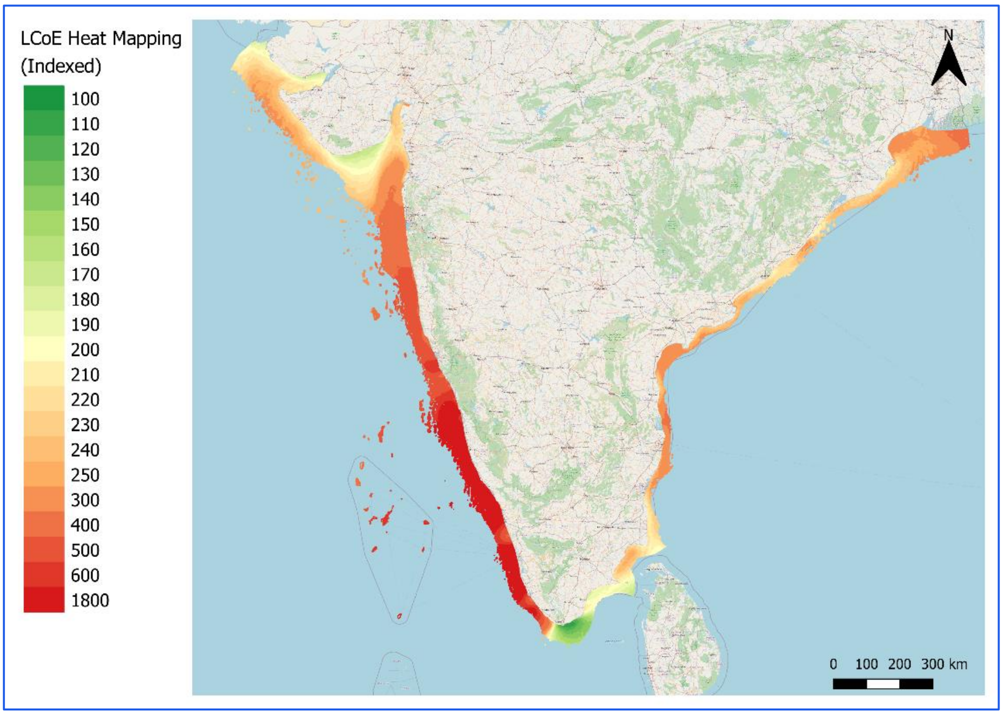
Appendix E. Overview of Engagement with Indian Stakeholders

Appendix A:

GIS Guide: Determining Offshore Wind Farms in India

14 February 2023

Centre of Excellence
for Offshore Wind and Renewable Energy


LCoE Heat Mapping
(Indexed)
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
300
400
500
600
1800
N
0 100 200 300 km

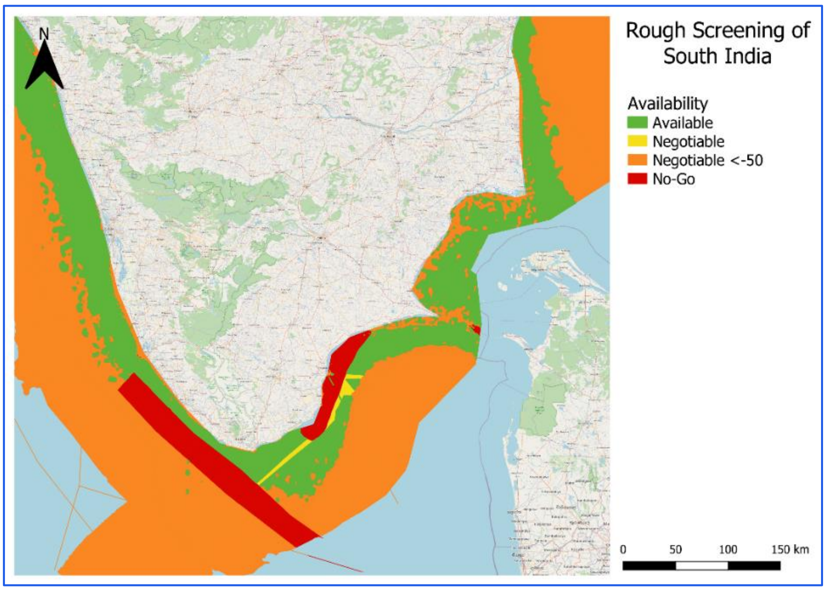

Rough Screening of
South India
Availability
Available
Negotiable
Negotiable <-50
No-Go
N
0 50 100 150 km

Table of Contents

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.

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**.

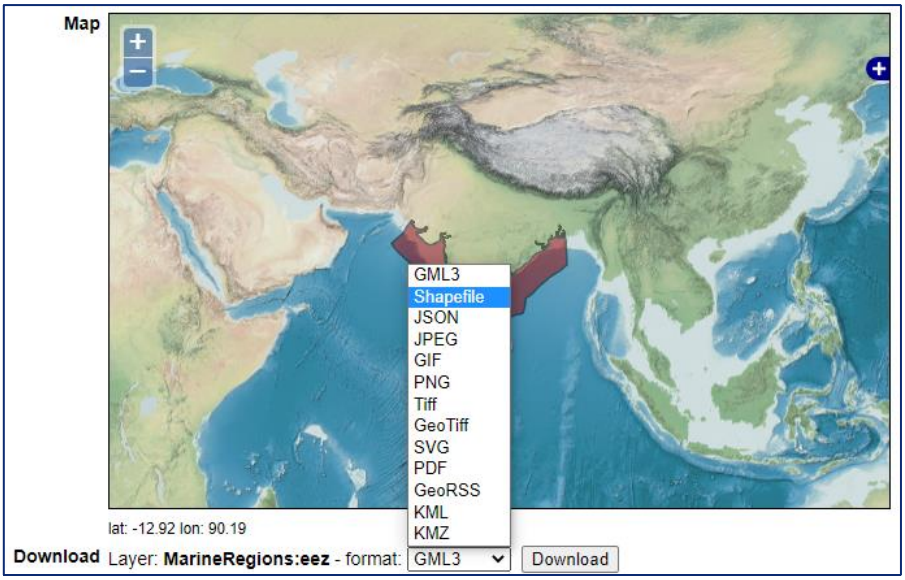
2.1 Step 1. Clip Your Data to a Mask Layer

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**

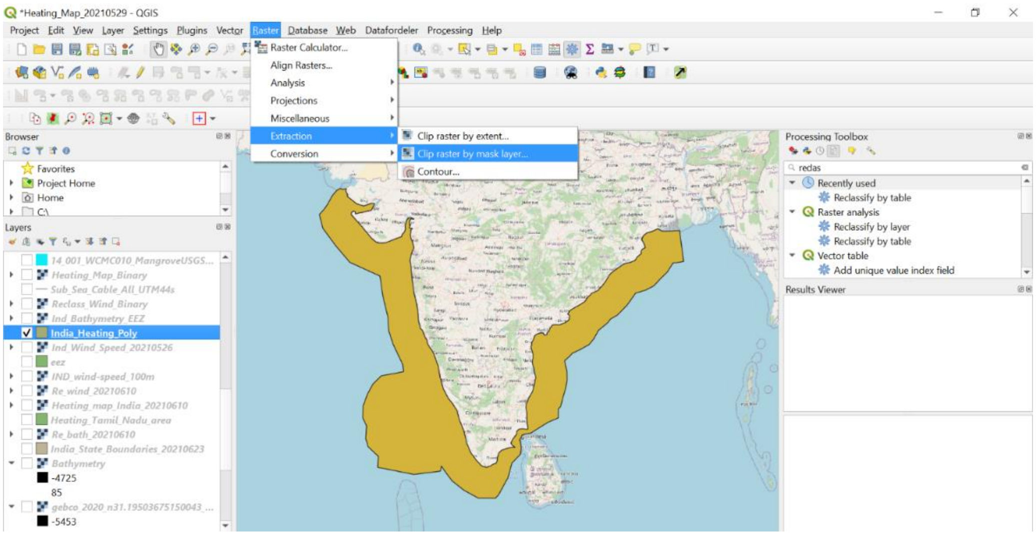


Figure 1: Clip by Mask Layer

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**.

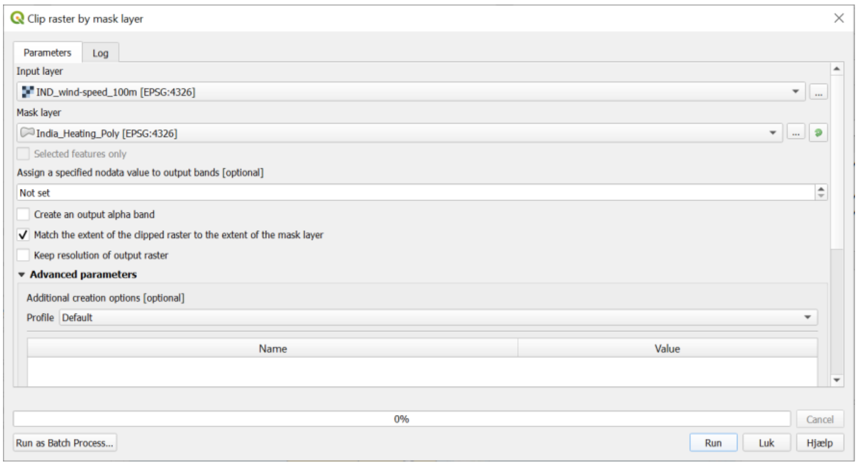


Figure 1.2: Clip by mask layer panel

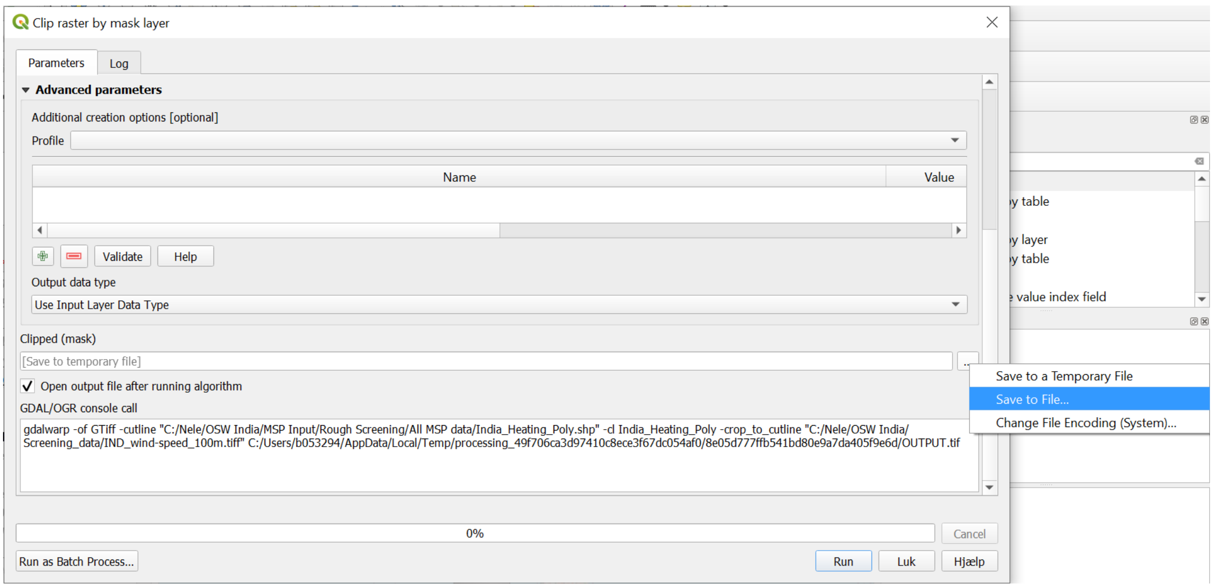


Figure 1.3: Clip by mask layer panel

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.

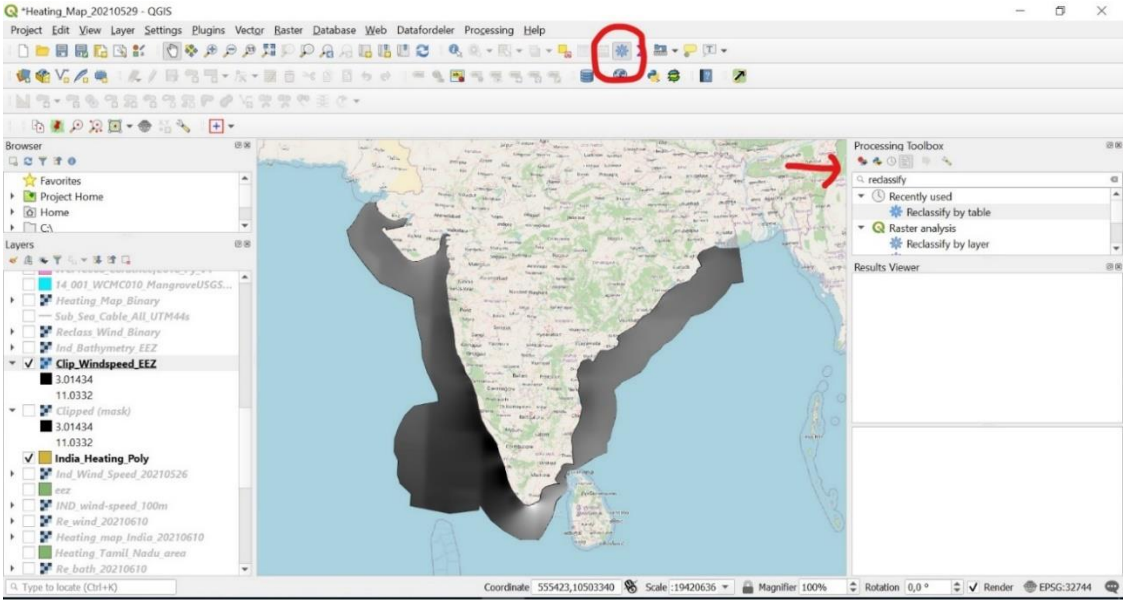


Figure 1.4: Clipped wind speed raster and processing toolbox

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.

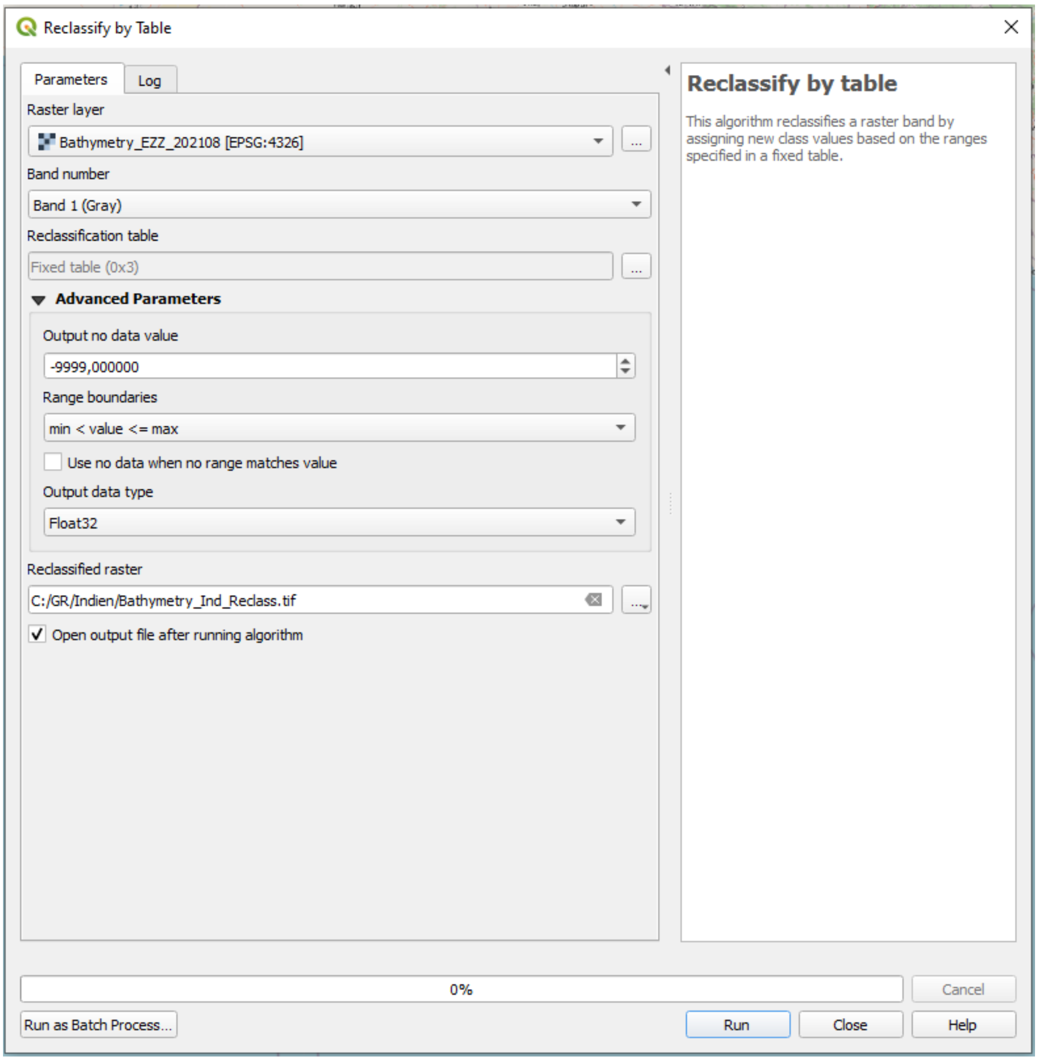


Figure 1.5 reclassify by table

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

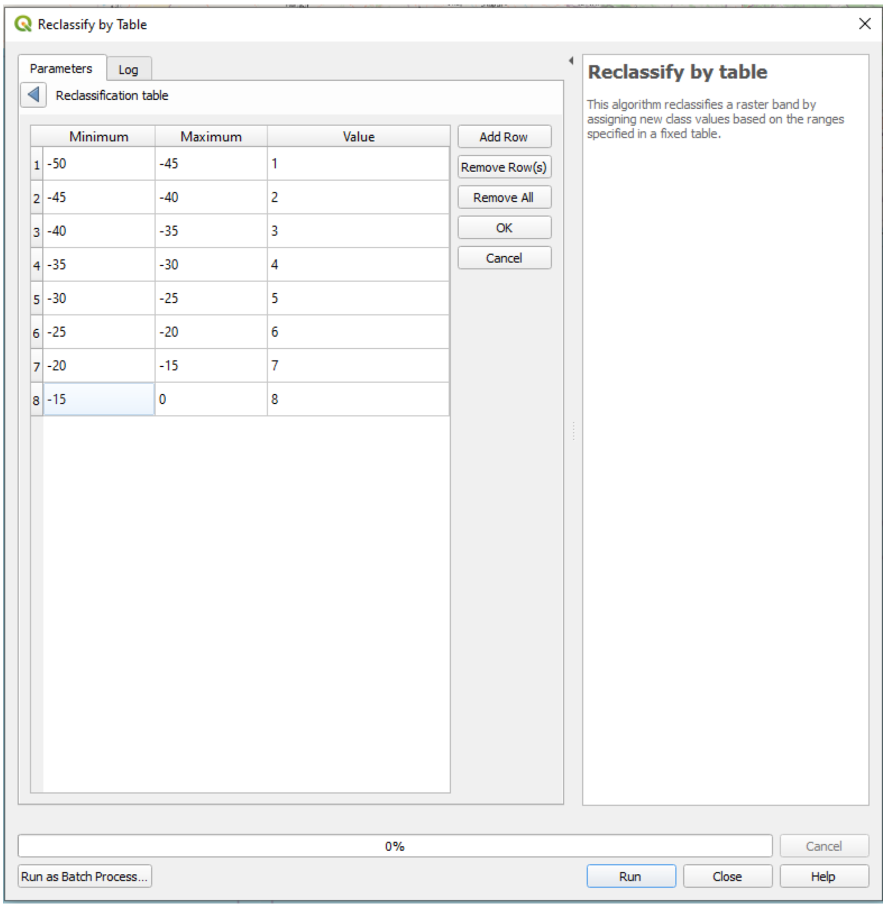


Figure 1.6 Example of the reclassify by table

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.

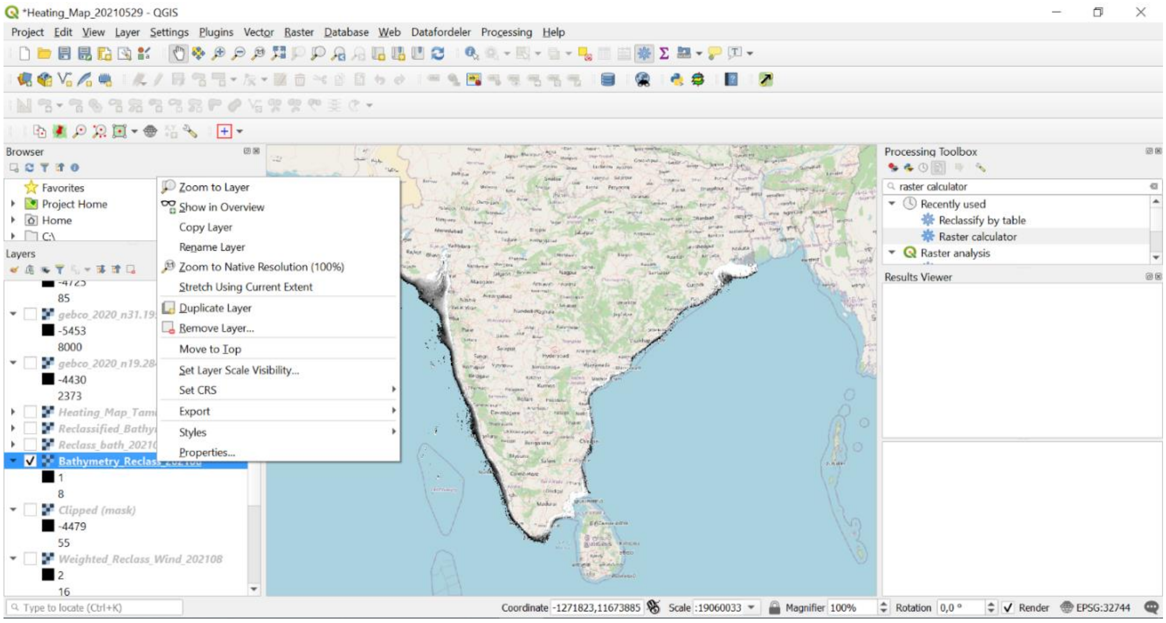


Figure 1.7: Example of reclassified bathymetry raster layer

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.

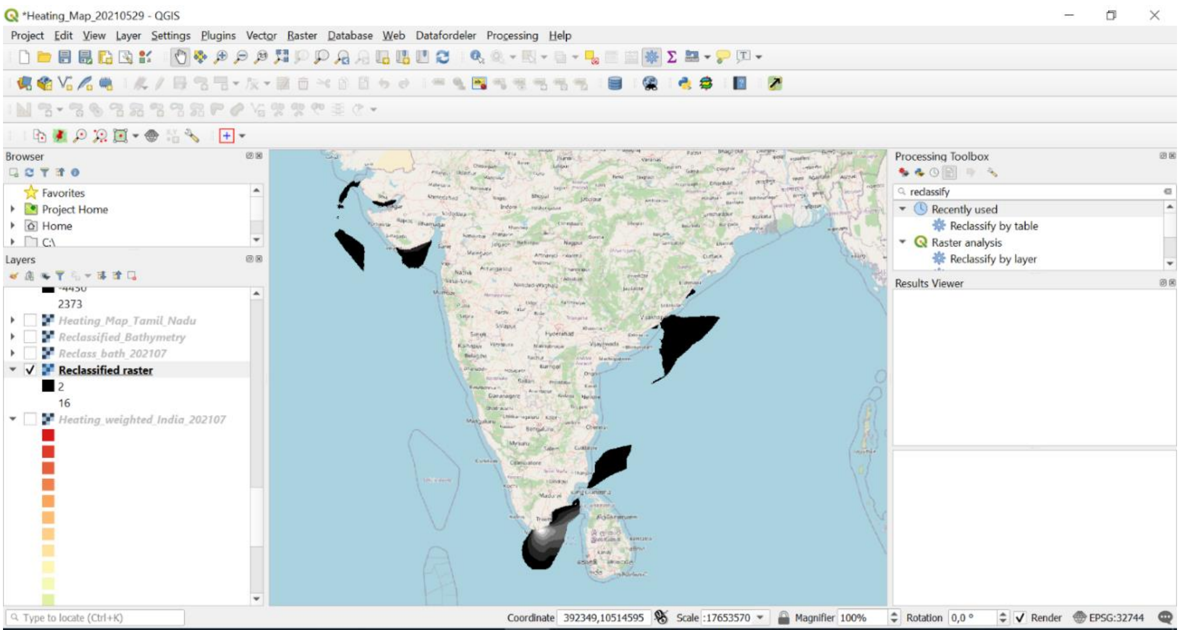


Figure 1.8: Example of reclassified wind speed layer.

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**.

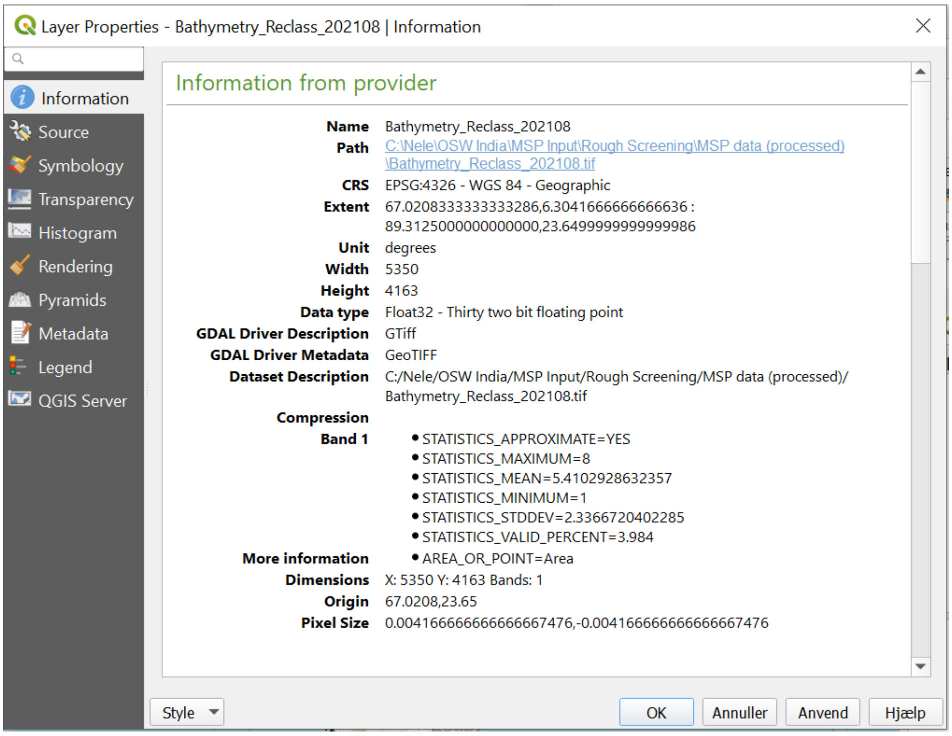


Figure 1.9: Layer properties

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.

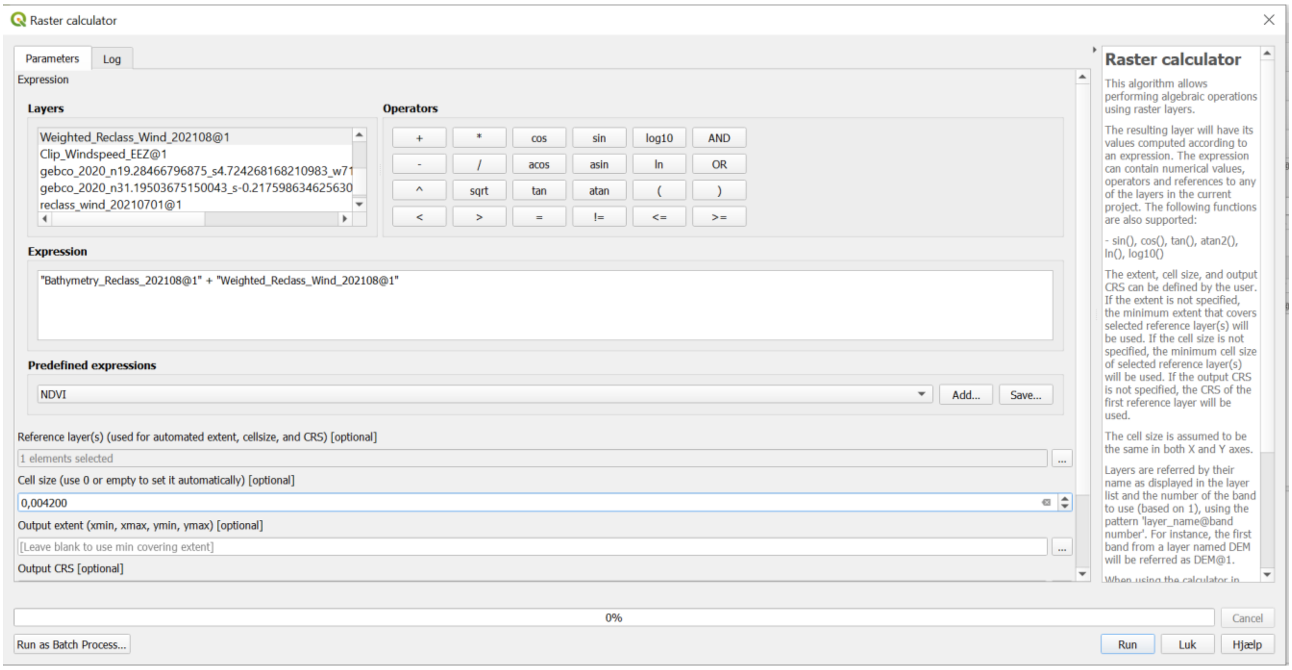


Figure 1.10: Raster calculator panel

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.

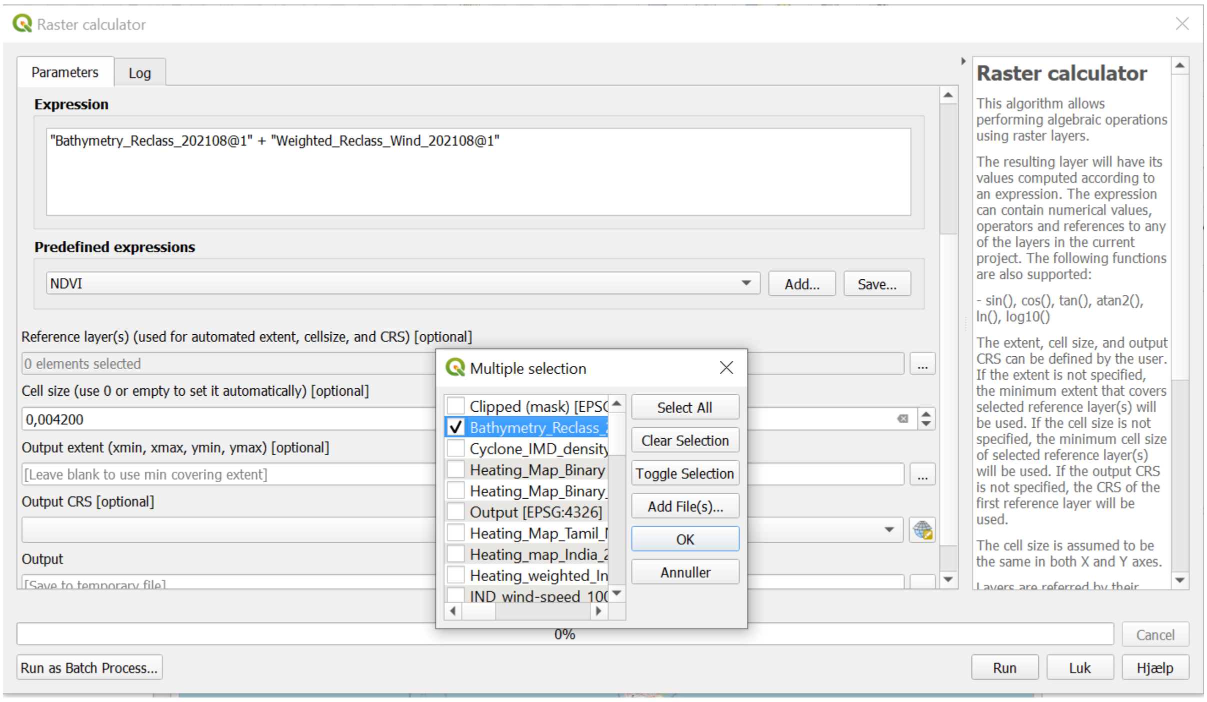


Figure 1.11: Raster calculator panel

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.

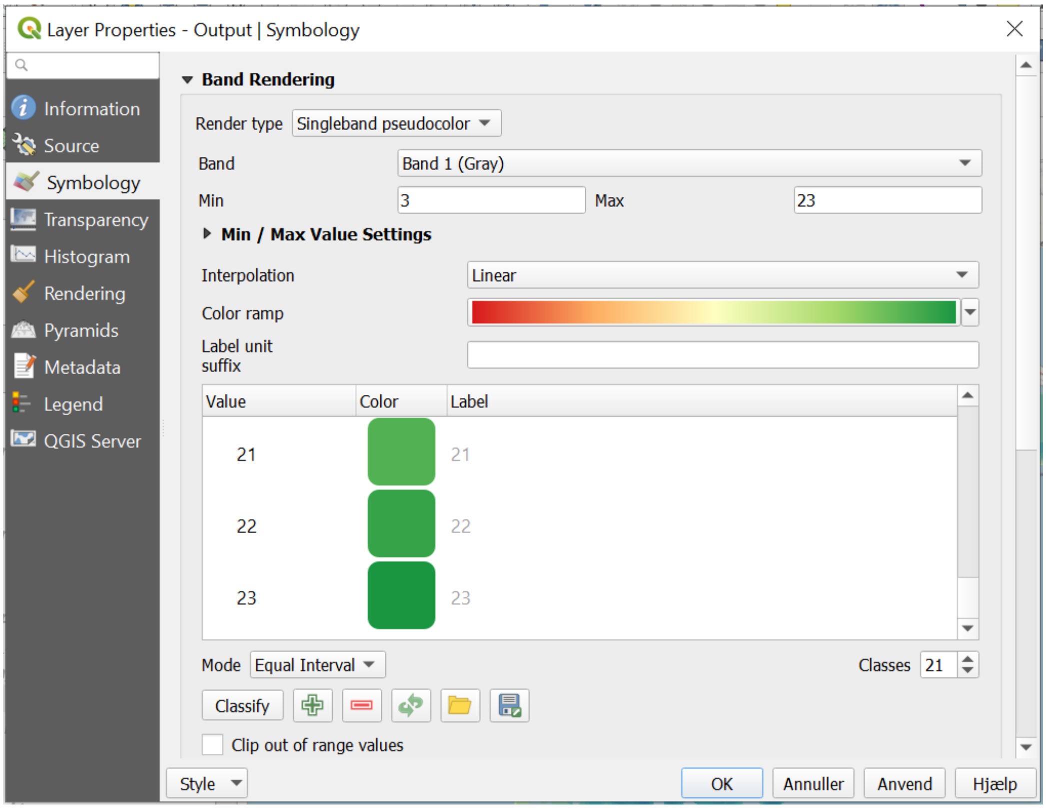


Figure 1.12: Layer properties: Symbology

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.

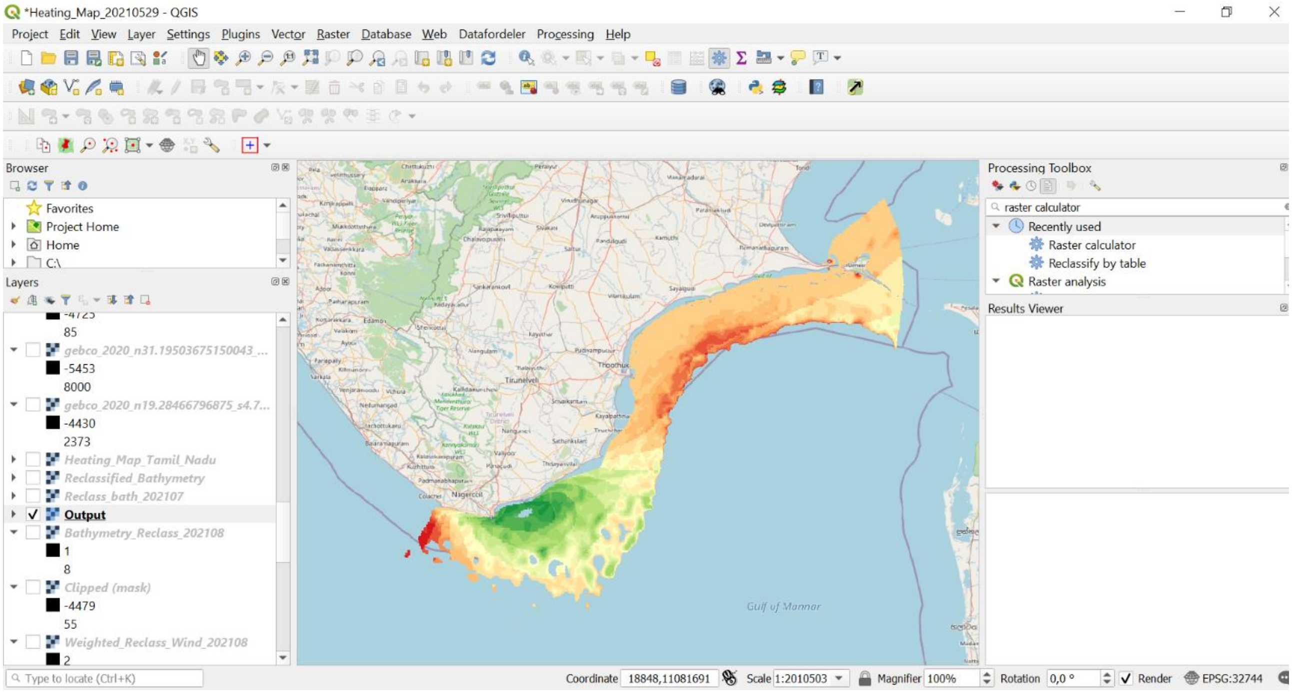


Figure 1.13: Finished heating map, zoomed in to south India.

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.

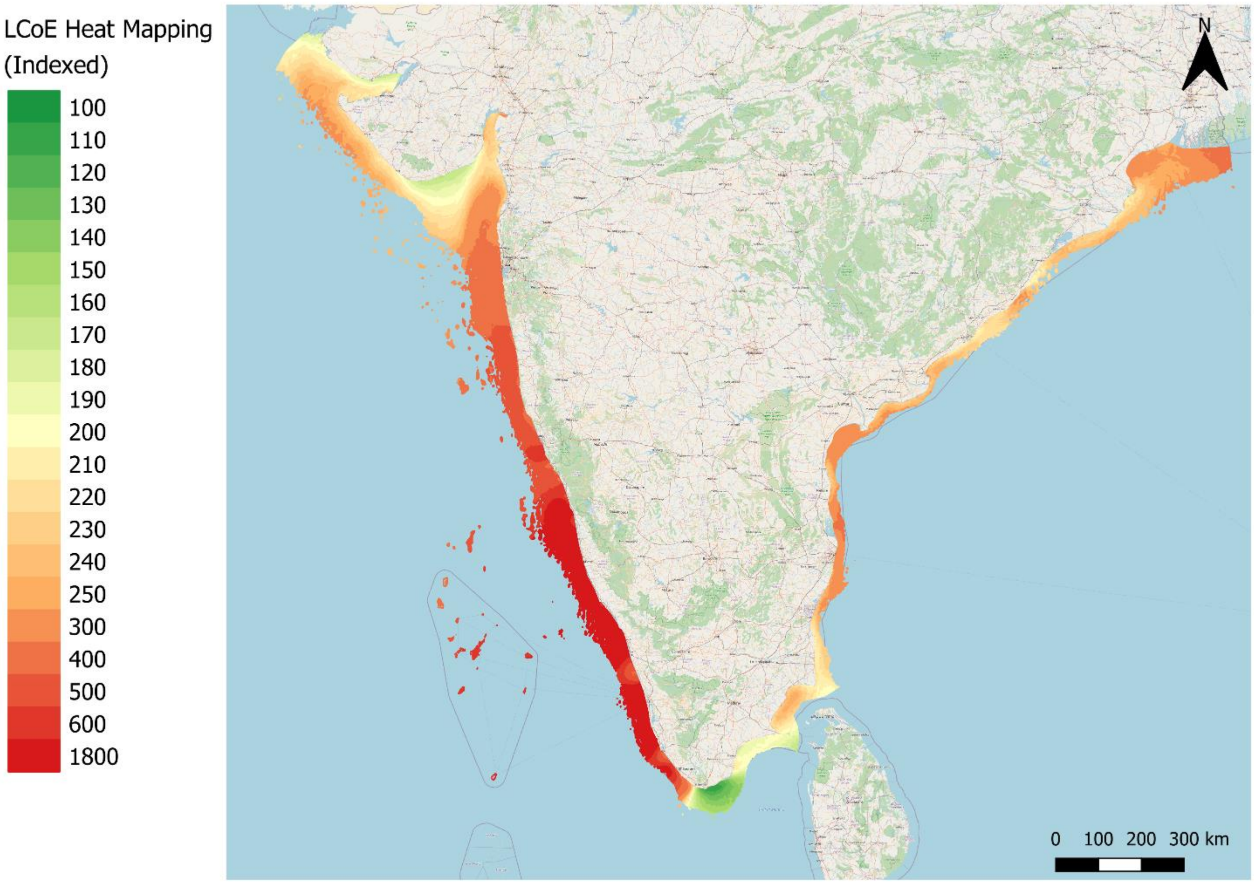


Table 2.: Data overview

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.

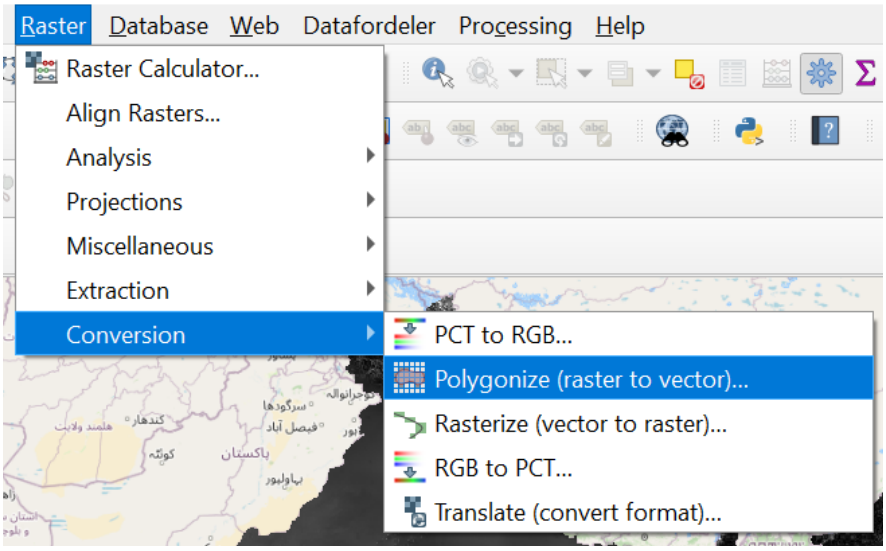


Figure 2: Polygonize (raster to vector)

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.

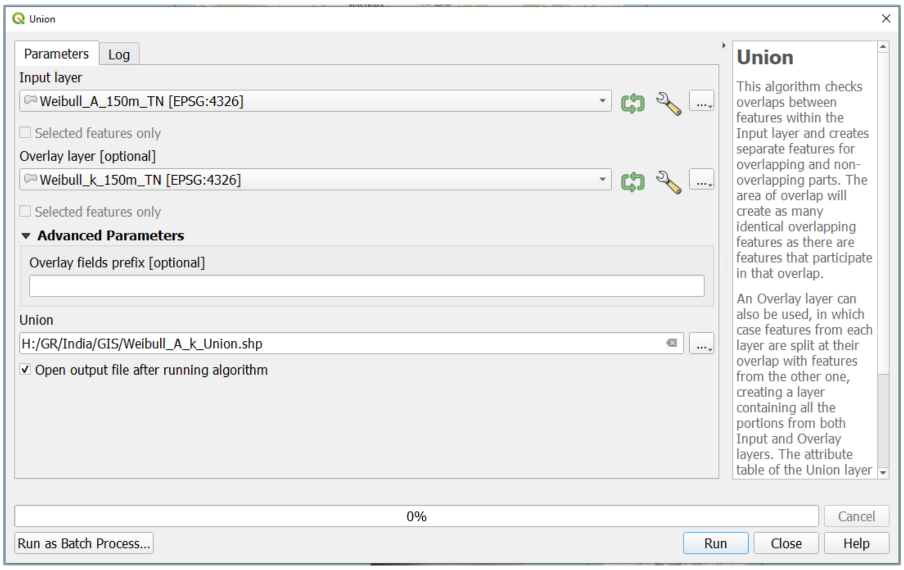


Figure 2.1: Union tool

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.

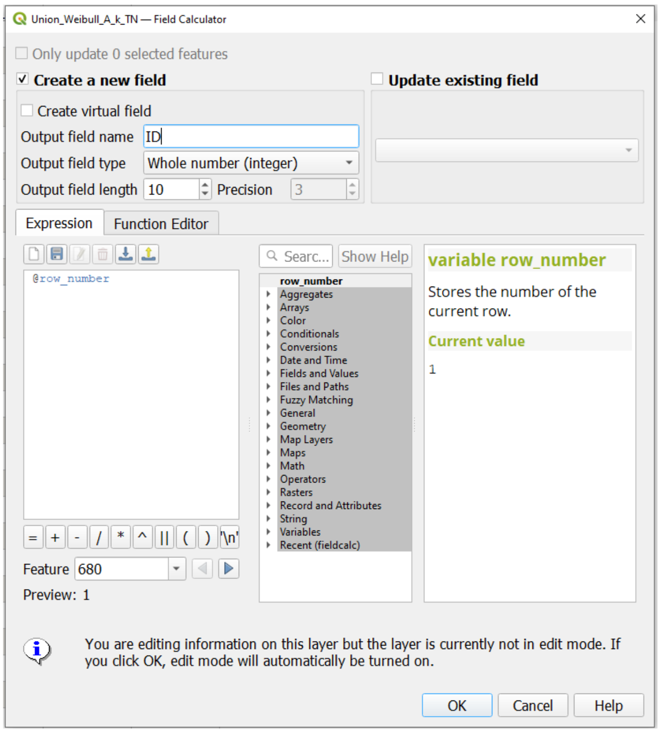


Figure 2.3: Field calculator – add row number

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.*

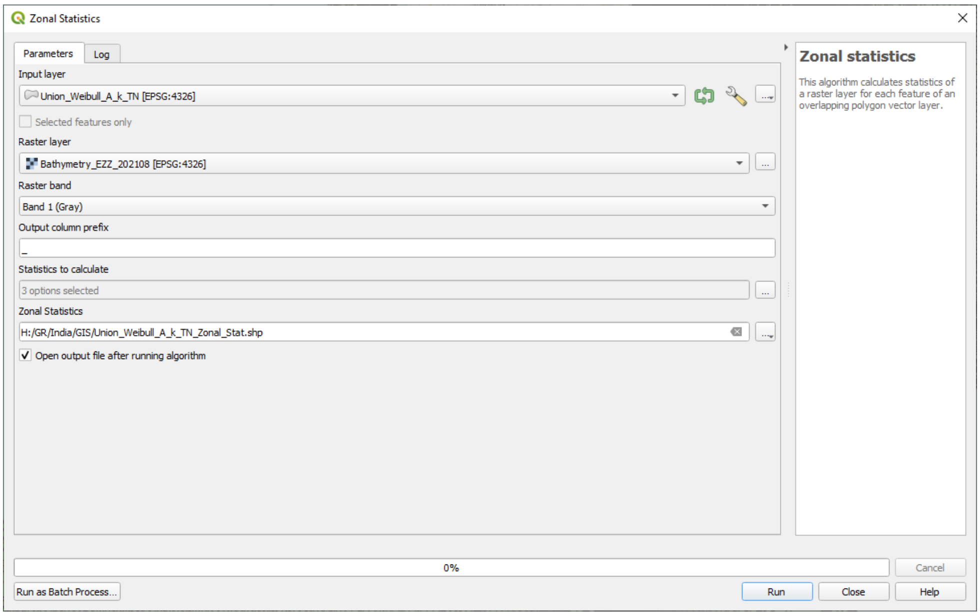


Figure 2.4: Zonal Statistics

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).

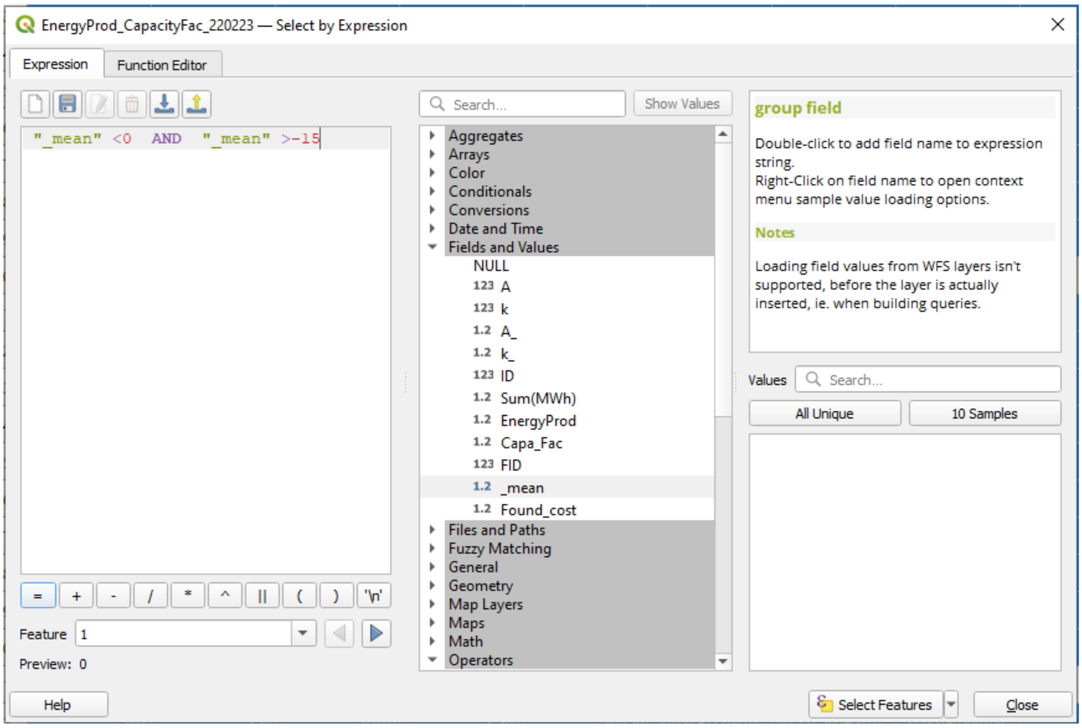


Figure 2.5: Select by expression

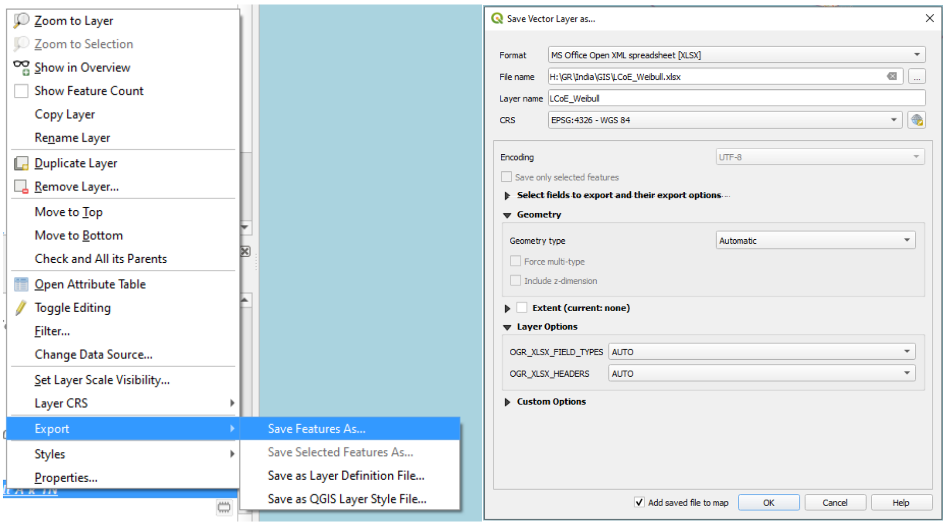
Next, we export the layer to Excel. With that done, we lastly need to add all other costs to the specified foundation cost (table 2) to get the **total investment cost**. The total investment cost is needed to calculate the CAPEX in step 3.

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.

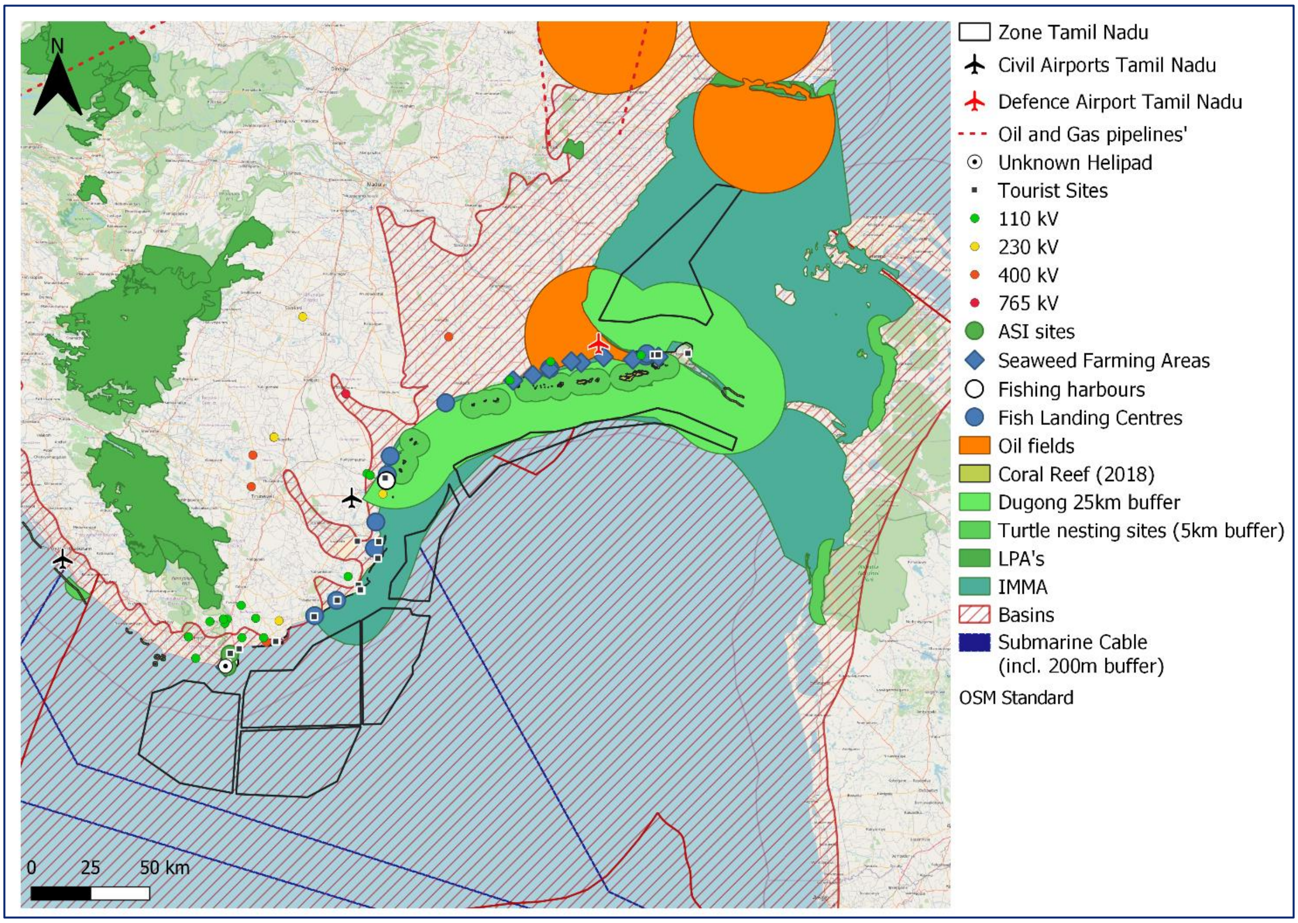


Figure 3: Restriction (negotiation) zones and no-go areas

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.

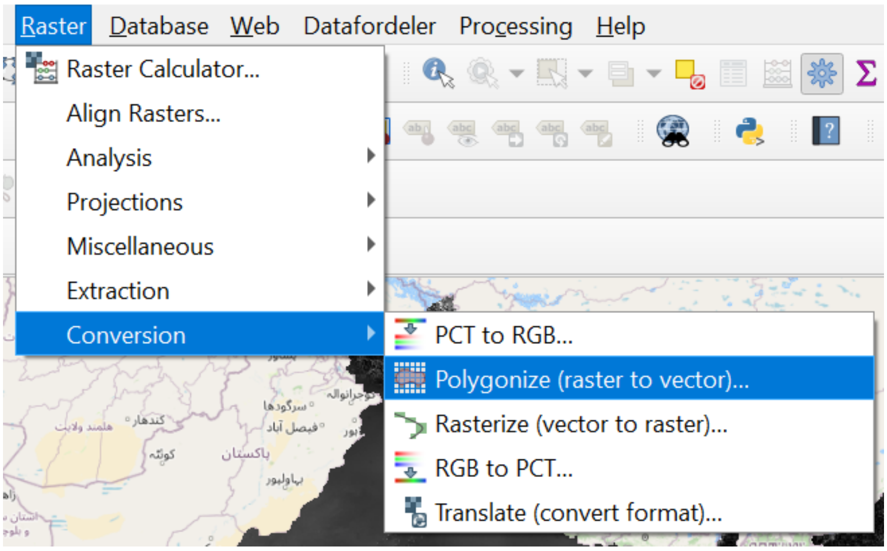


Figure 3: Polygonize (raster to vector)

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

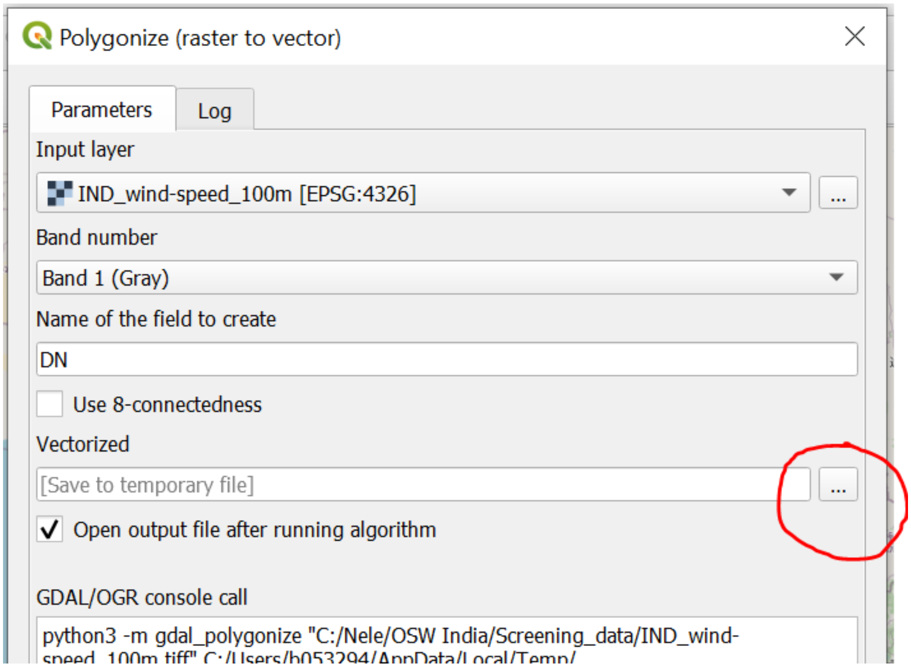


Figure 3.2: Polygonize (raster to vector)

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

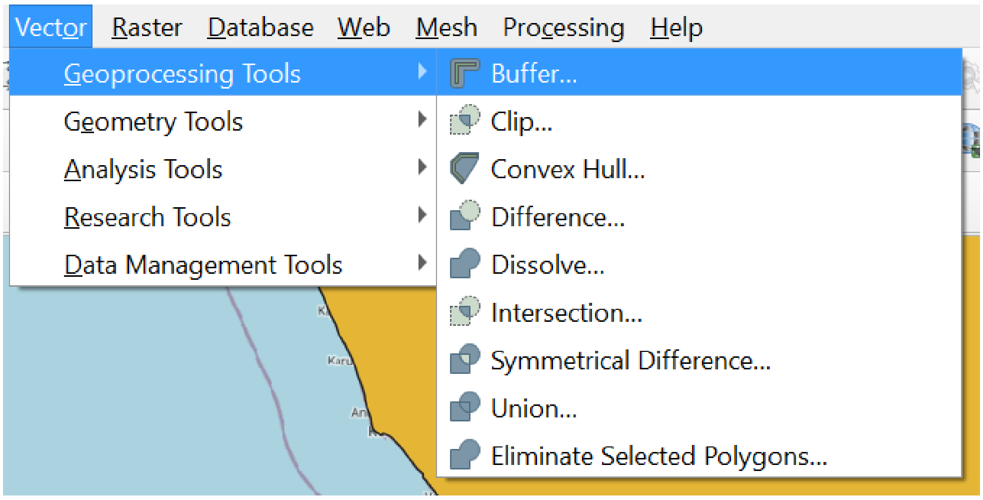


Figure 3.3: How to find the 'Buffer' geoprocessing tool

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

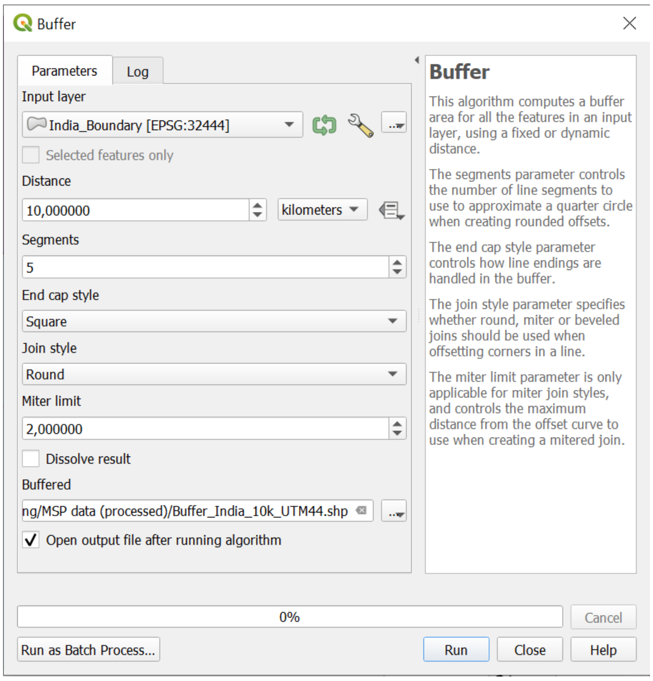


Figure 3.4: Insert parameters for the 'Buffer-tool' in QGIS

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.

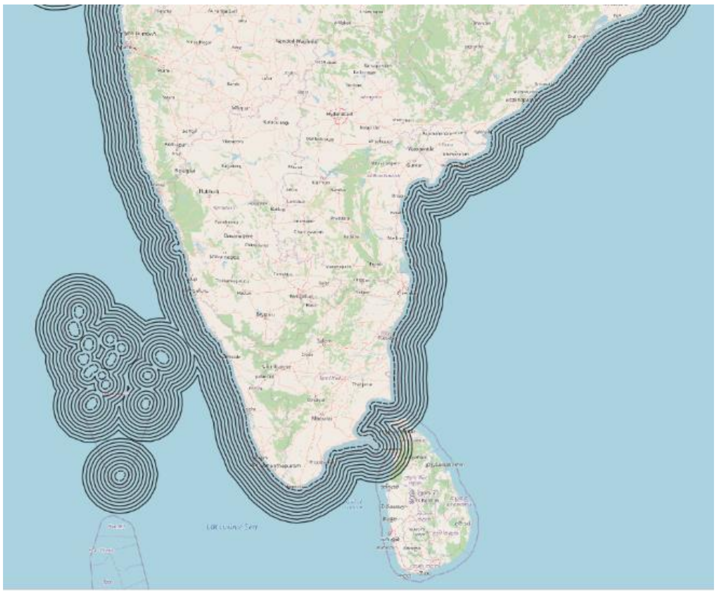


Figure 3.5: The 10 buffer layers (10-100km from the coast)

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**.

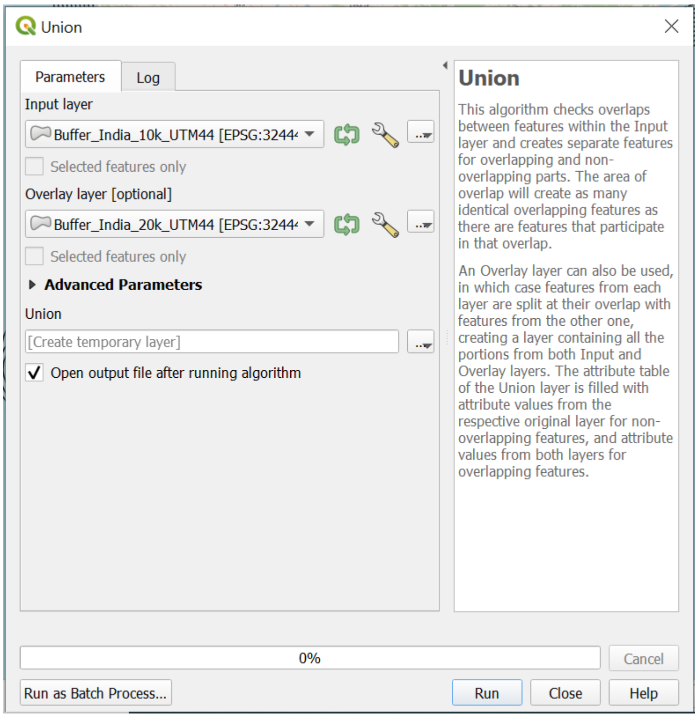


Figure 3.6: The 'Union-tool' in QGIS

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.

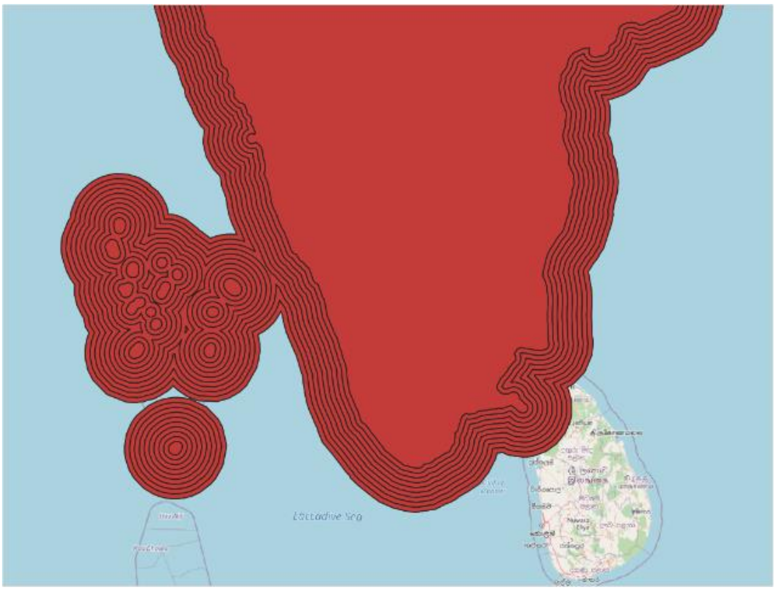
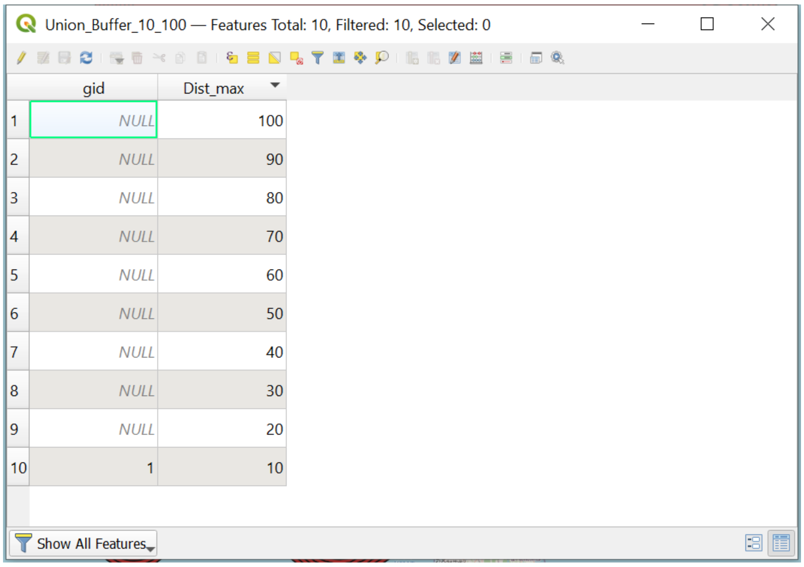


Figure 3.7: Example of the unified buffers (10-100km from the coast)

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.*



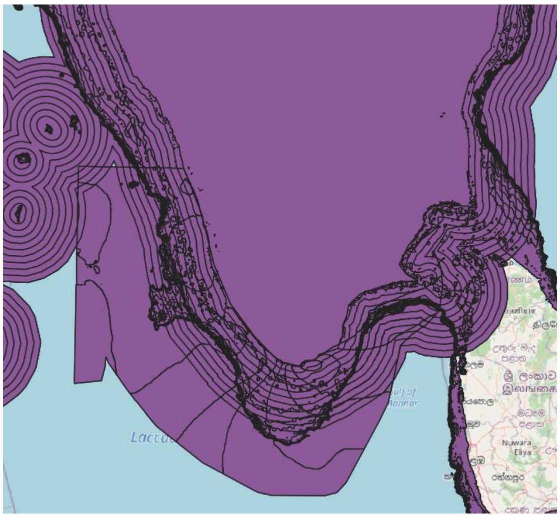
	gid	Dist_max
1	NULL	100
2	NULL	90
3	NULL	80
4	NULL	70
5	NULL	60
6	NULL	50
7	NULL	40
8	NULL	30
9	NULL	20
10	1	10

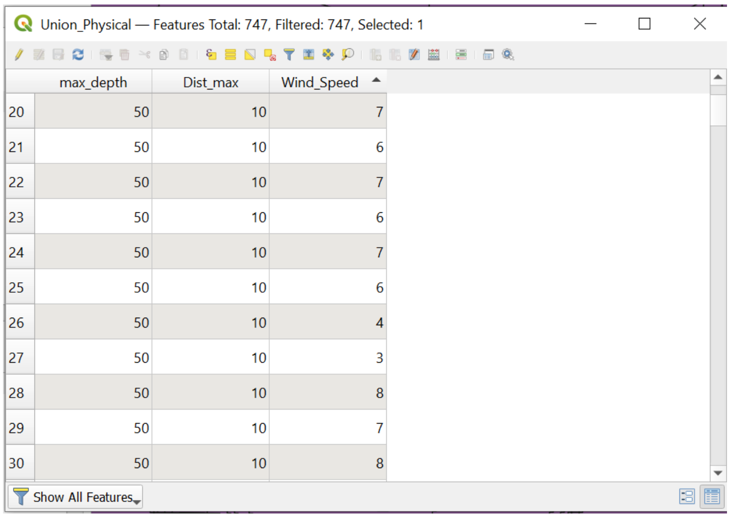
3.8: Attribute table of the unified buffer-layer in QGIS

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

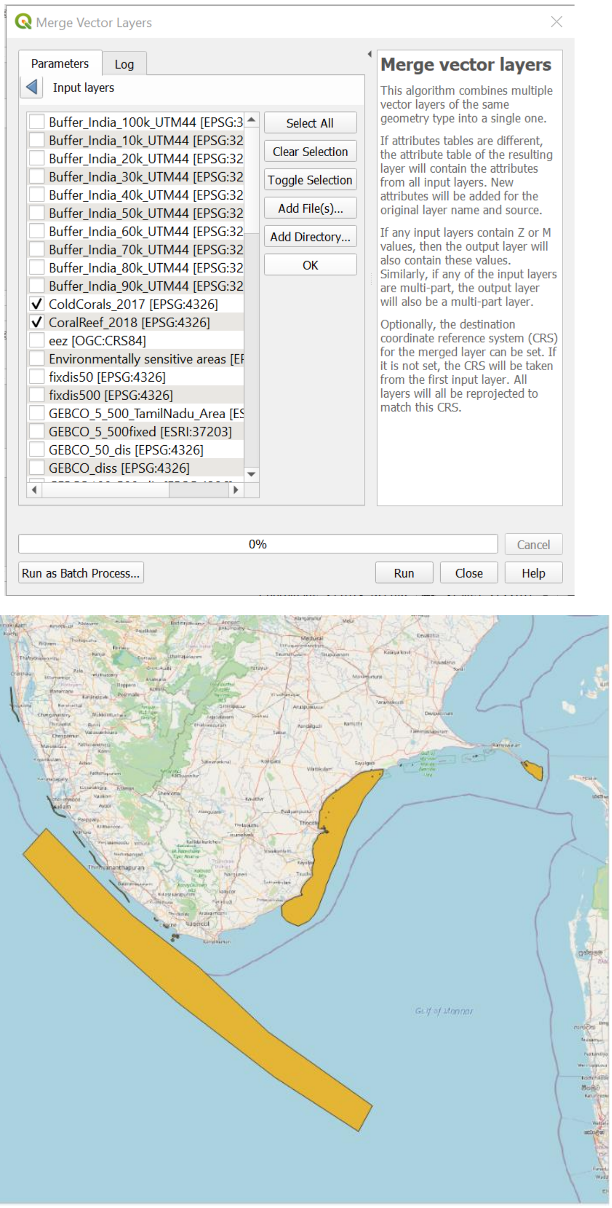
Figure 3.9: Example of the unified layer of the relevant physical limitations (left) and attribute table (right)

4.3.2 Creating one layer combining all no-go areas

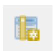
To combine all data of no-go areas we simply want to **merge** all relevant layers and add a new field in the attribute table where we specify that these area are not available.

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.

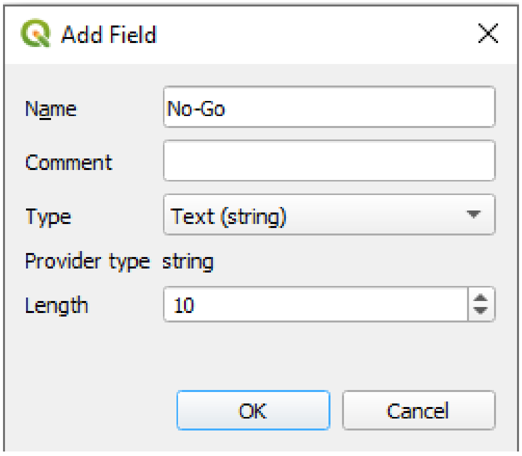


Figure 3.11: 'Add field' window in QGIS

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.

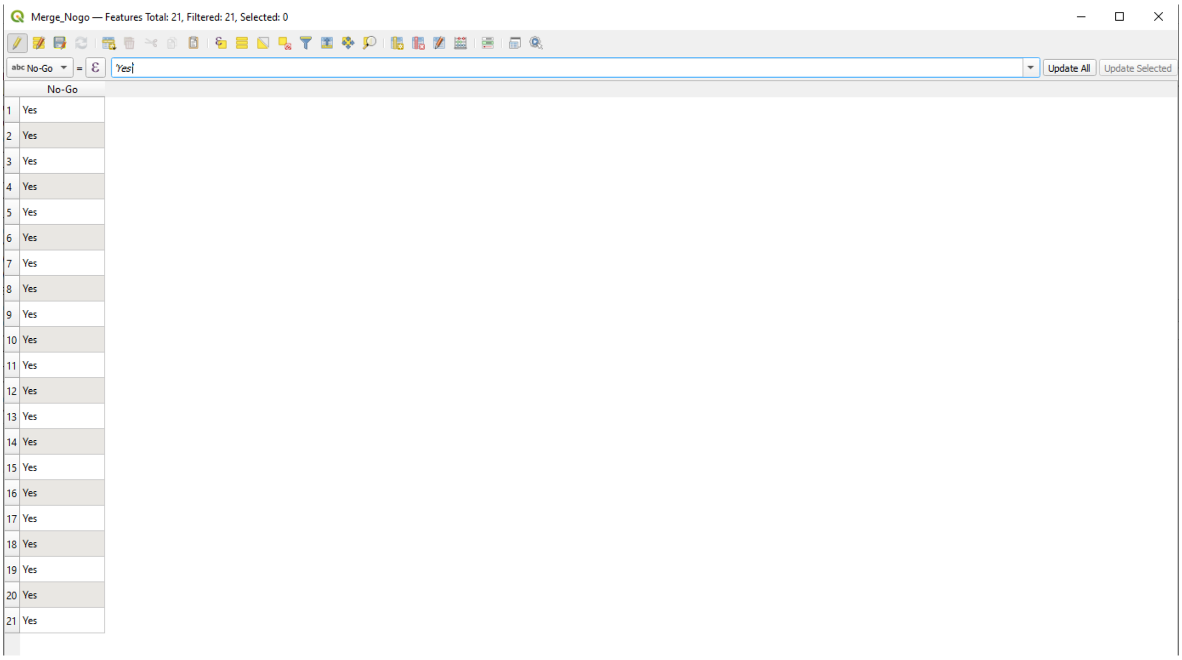
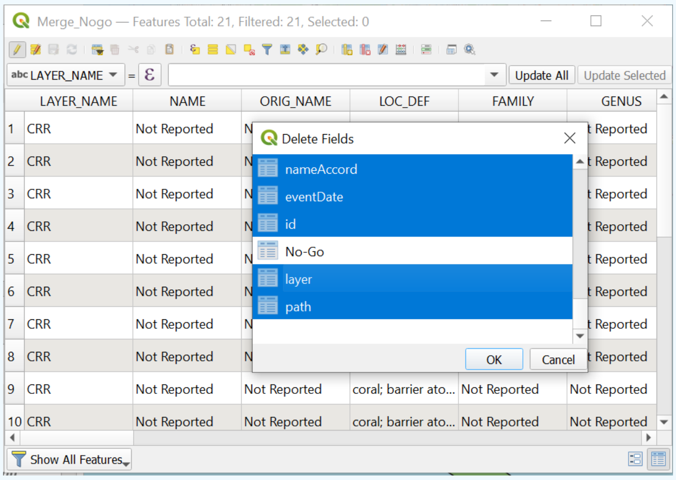


Figure 3.12: Attribute table for the 'no-go'-layer

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.

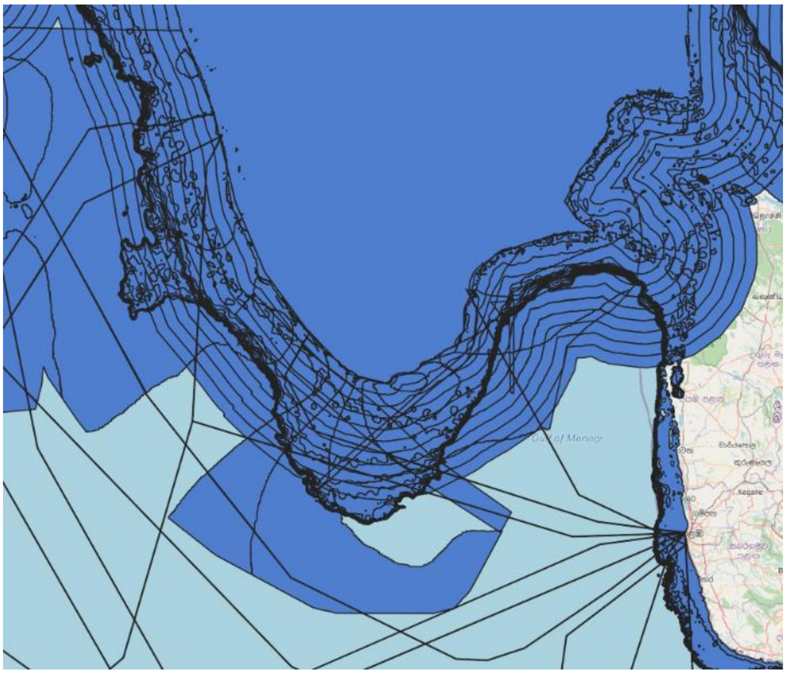


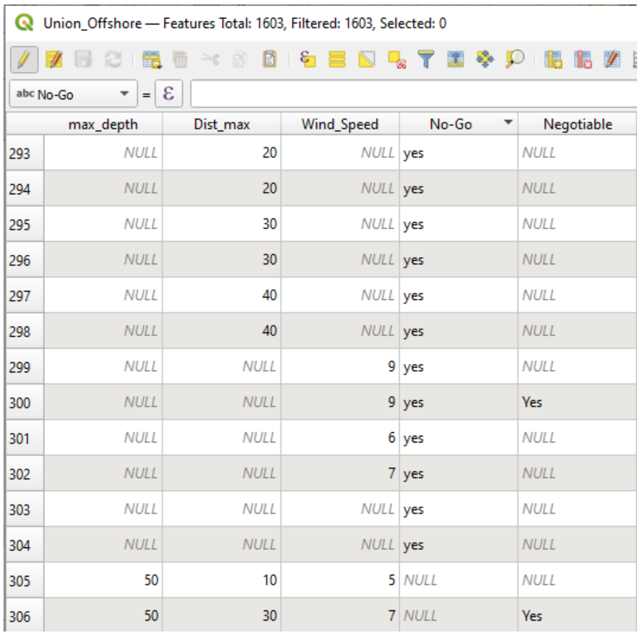
Figure 3.13: Example of the final output layer with all data unified

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’**

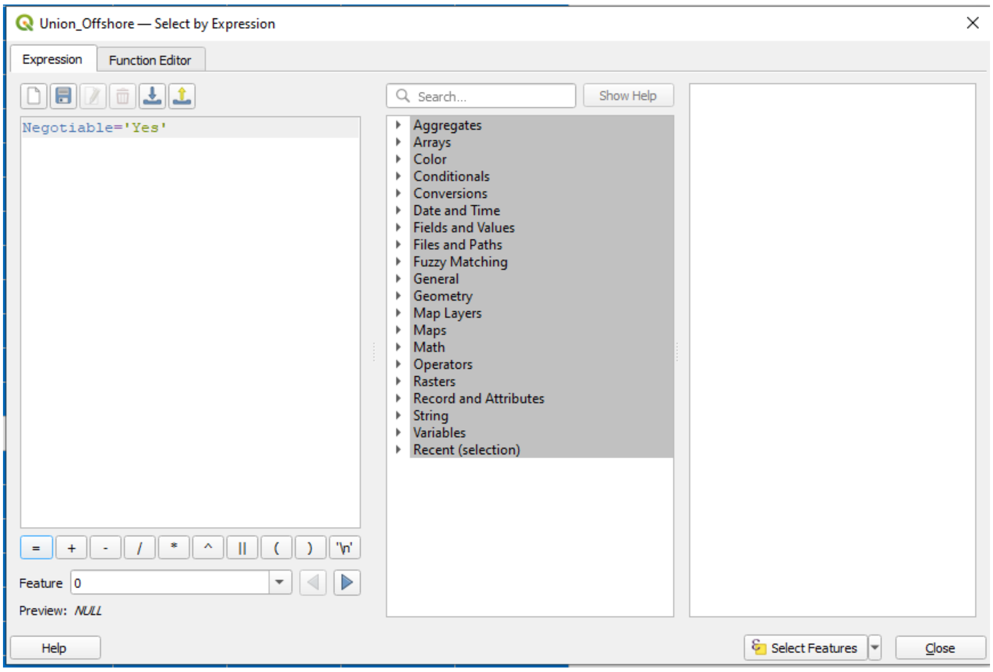


	max_depth	Dist_max	Wind_Speed	No-Go	Negotiable
293	NULL	20	NULL	yes	NULL
294	NULL	20	NULL	yes	NULL
295	NULL	30	NULL	yes	NULL
296	NULL	30	NULL	yes	NULL
297	NULL	40	NULL	yes	NULL
298	NULL	40	NULL	yes	NULL
299	NULL	NULL	9	yes	NULL
300	NULL	NULL	9	yes	Yes
301	NULL	NULL	6	yes	NULL
302	NULL	NULL	7	yes	NULL
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

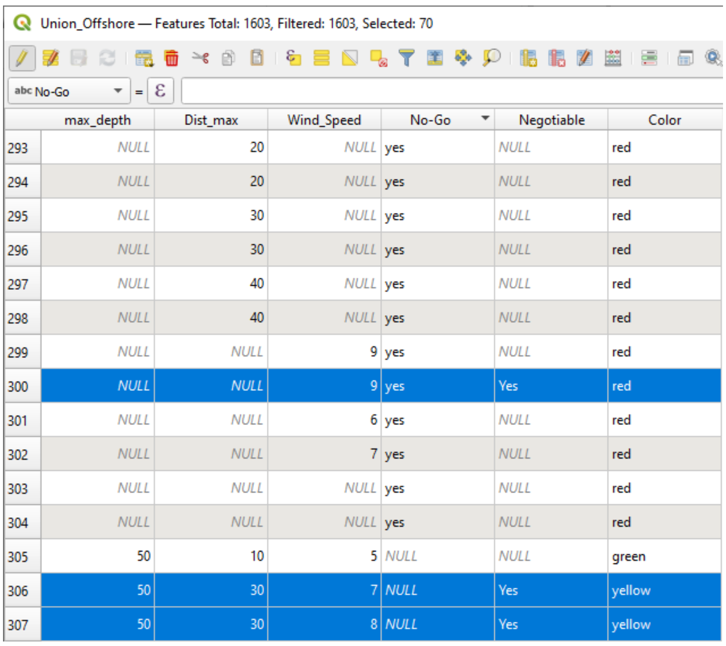
Open the attribute table and **enable editing**, click on **select features by expression**. A window should pop up where you can write an expression that enables you to select specific values. To do so write an expression like the one exemplified in figure 2.15.

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**.

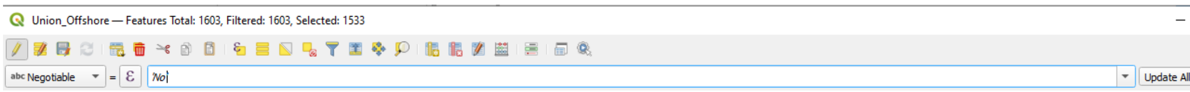


Figure 2.17: Expression dialog panel in the attribute table

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.

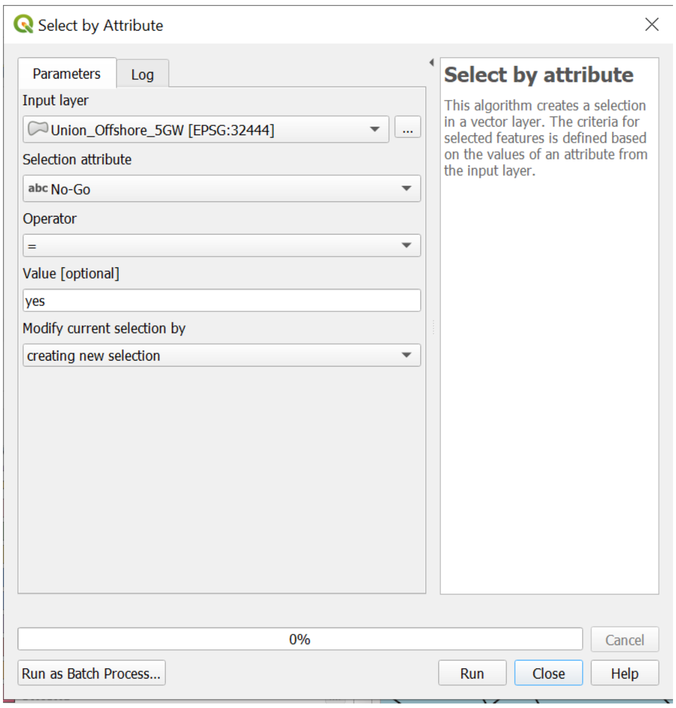


Figure 2.18: 'Select by Attribute' window in QGIS

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.

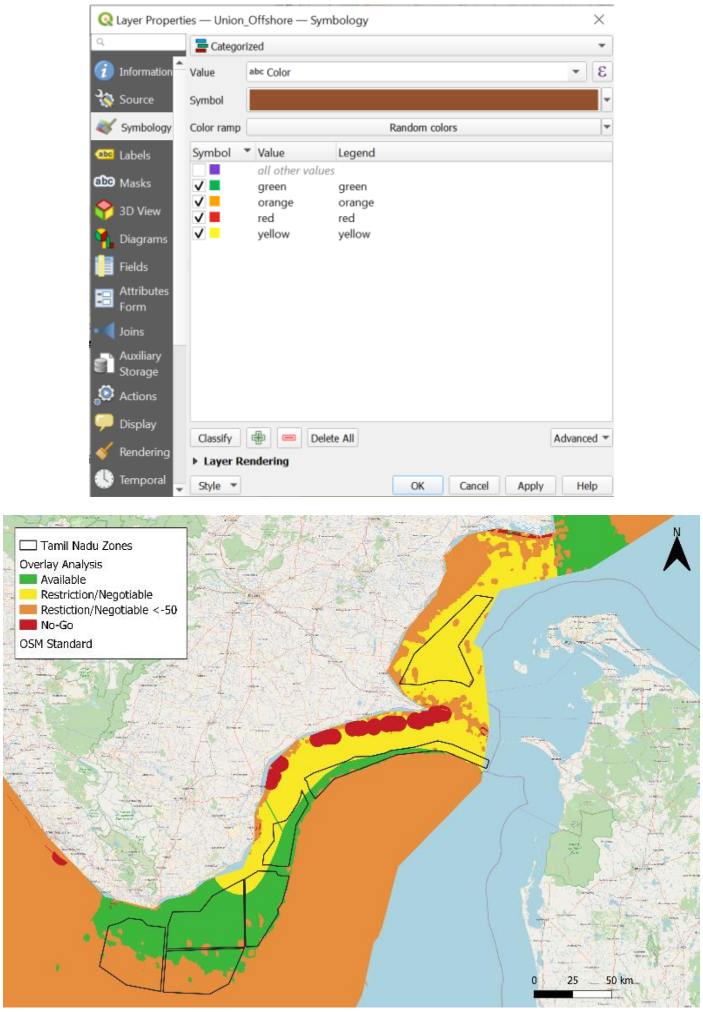


Figure 2.10: Layer properties window of the final output layer (left) and the color scheme applied on the final output layer

Appendix B:

Concept / System Description of an Offshore Wind Farm

18 November 2022

Centre of Excellence
for Offshore Wind and Renewable Energy

Table of Contents

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)

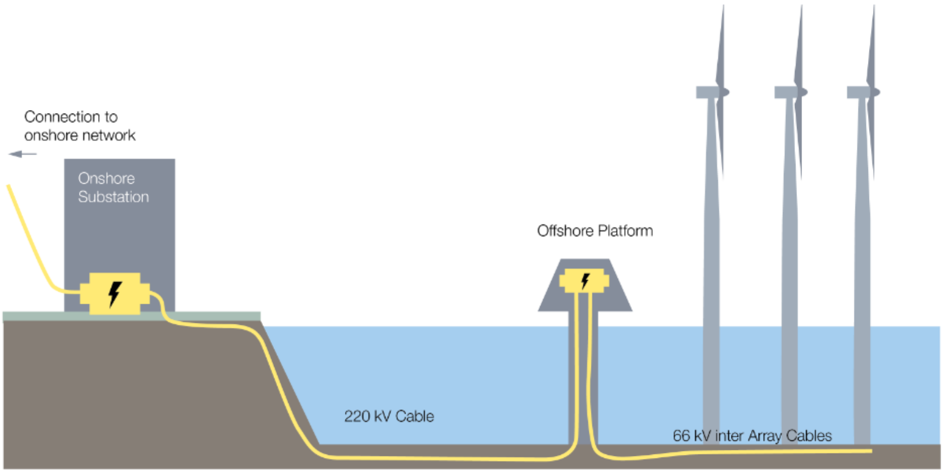


Figure 1-1| Overview of the physical elements of an offshore wind farm (COWI, 2021)

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.

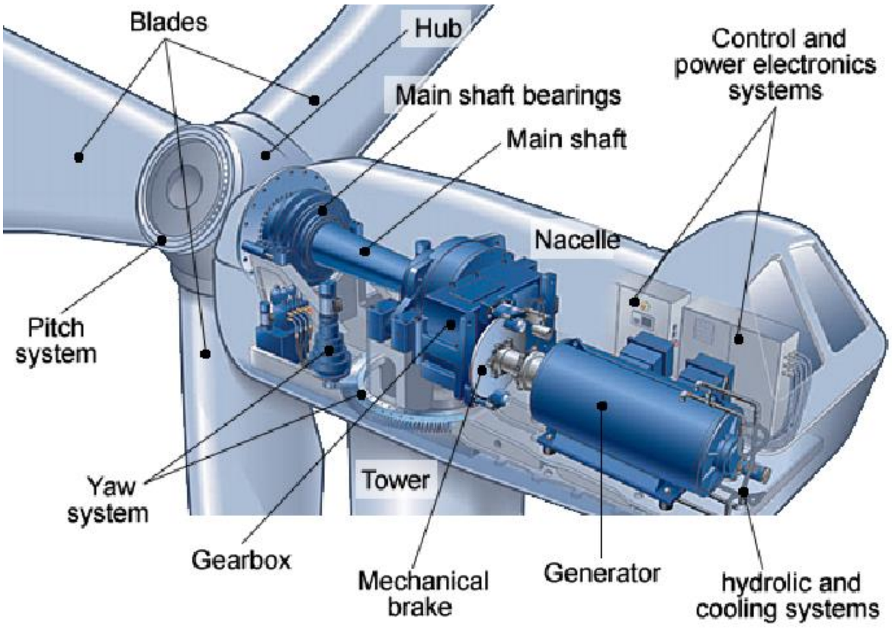


Figure 2-1 | Main components in an offshore wind turbine (Tchakoua, Wamkeue, & Theubou, 2013) in the concept/system sub-report)

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.

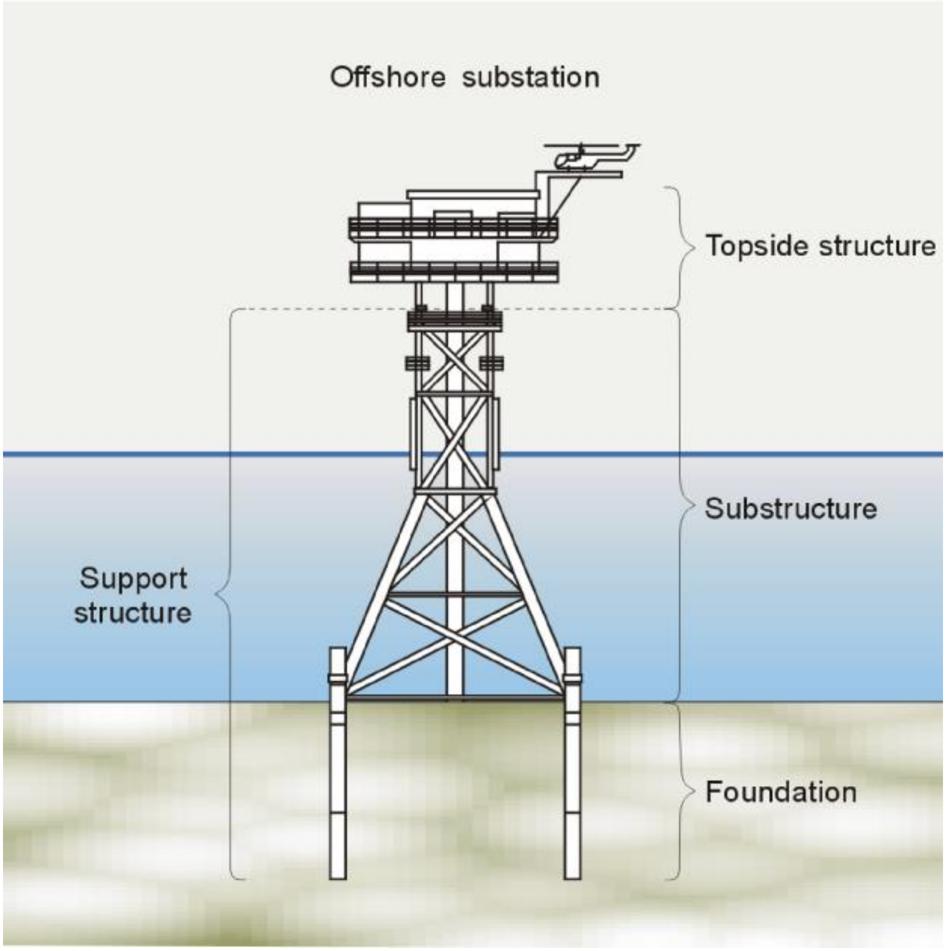


Figure 3-1 | A schematic of a typical offshore substation (Robak & Raczkowski, 2018) in the concept/system sub-report)

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.

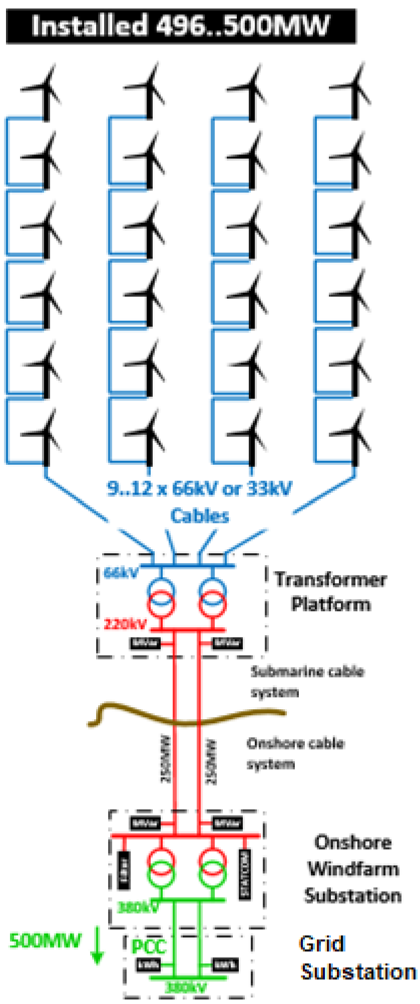


Figure 4-1 | Typical Transmission System with Offshore Substation (COWI, 2021)

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.

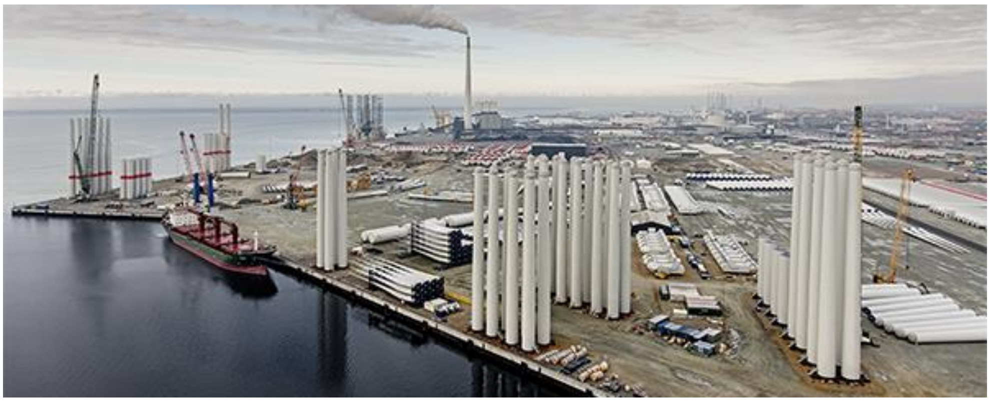


Figure 5-1 | Port of Esbjerg in Denmark load out facilities (Esberg)

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.

Appendix C:

Technical Note on Marine Traffic Systems in Tamil Nadu

21 September 2022

Centre of Excellence
for Offshore Wind and Renewable Energy

Table of Contents

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. This 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 of the assignment is to support Ministry of New and Renewable Energy (MNRE) in their work for the implementation of 30 GW offshore wind by 2030. As a part of this initiative, DEA is assisting the Government of India in conducting a Marine Spatial Planning (MSP) for potential areas for offshore wind development around the southern cost of Tamil Nadu.

The main objective of the MSP for Tamil Nadu is to notify the most suitable zones for deployment of offshore wind in India in Tamil Nadu in accordance with the renewable policy and nationwide target of 30 GW offshore wind by 2030.

The analysis conducted has identified marine traffic as a key constraint and significant competing users within the OWF Zone in Tamil Nadu. This potential conflict was further analysed and have led to narrowing down the zones to a shortlisted site measuring ~3500 Km^2, while adopting the principles of co-existence with competing users.

Accordingly, this technical note provides an overview of marine traffic assessment conducted as a part of MSP for Tamil Nadu.

2. Background

Shipping is an important and growing maritime sector for India, that needs safe and efficient operating conditions. Maritime traffic and offshore wind can come into conflict if new offshore wind farms are to be built in areas with intensive shipping activity. Therefore, fixed installations such as offshore wind farms are a particular issue for maritime transport industry if they are in direct conflict and impede safe and efficient transportation. OWF limit the area where ships can navigate and increases traffic density at other locations. The international shipping lanes would be considered as restricted areas and exclusion zones where no offshore wind development is possible.

2.1 Rough screening

Initially, a rough screening was carried out for offshore wind sites in Tamil Nadu based on open-source data from IMF / World Bank (IMF, 2021) and is illustrated in Figure 2-1

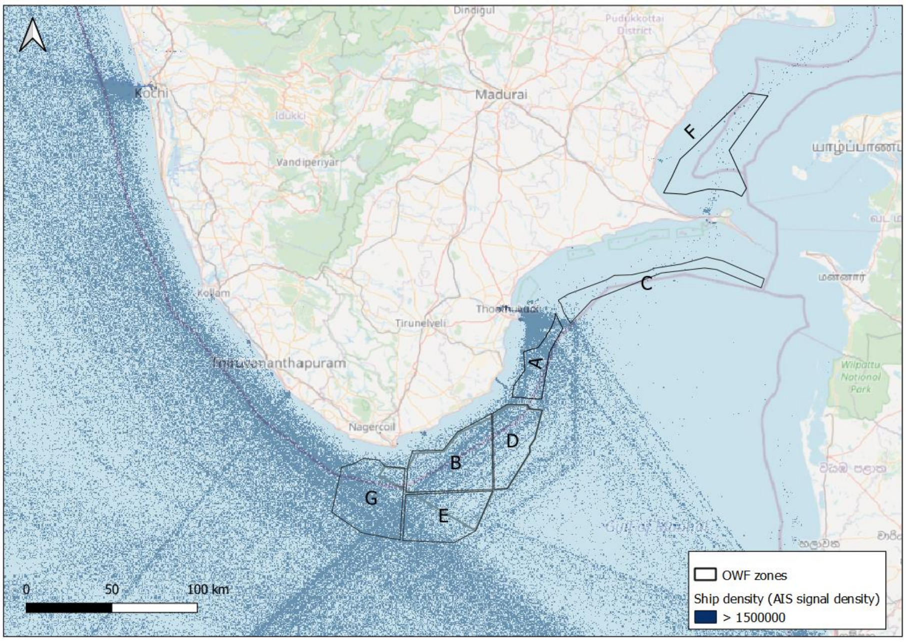


Figure 2-1 : Ship traffic plots based on Global Ship Traffic Data 2015-2020 (Source: World Bank / IMF data set)

The initial assessment indicated that a significant amount of commercial marine traffic appears to pass through and around the identified zones potential offshore wind areas in Tamil Nadu. With regards to the Global Shipping Traffic Density the data is divided in the following categories:

Category	Types
Commercial	This includes e.g. bulk carrier, general cargo, tug, offshore supply ship, containing ship, tankers, supply vessel etc.
Fishing	Fishing vessel, trawler
Oil and Gas	Floating storage/production, drilling jack-up, drilling rig, well stimulation vessel
Passenger	Passenger ship
Pleasure	Yacht, sailing vessel

Although, it was not possible to conduct a detailed assessment in terms of shipping route density for various types of marine vessels, the following distinct sailing routes were identified:

- An international marine traffic route that runs in North west - south east direction, consisting of ship traffic connecting major transportation hubs / ports in Middle east, North Africa, western India to Malacca straits circumventing Sri Lanka.
- Marine traffic towards Port of Colombo
- Commercial Shipping traffic primarily between Tuticorin port and Male (Maldives) in northeast and southwest direction

2.2 Tuticorin Port

Tuticorin Port was requested to provide data on ship traffic handled at the port and is provided in Table 2-1 below. Based on this data it was concluded that, Tuticorin port handles a modest traffic of approximately 7 ships / day.

Table 2-1 Ship traffic data at Tuticorin Port (Source: Port of Tuticorin)

SI. No.	Year	Inward	Outward	Total
1	April 2018 to March 2019	1276	1259	2535
2	April 2019 to March 2020	1319	1304	2623
3	April 2020 to March 2021	1262	1237	2499
	Total	3857	3800	7657

Based on rough screening, it was considered prudent that a detailed analysis is conducted to fully understand the marine traffic patterns in the study area and include such assessment in marine spatial planning for OWF zones off coast Tamil Nadu (discussed in next section).

3. Traffic Intensity Distribution

3.1 AIS dataset and analysis approach

In order to obtain a comprehensive picture of the marine traffic in and around the OWF zones, AIS data was procured from marinetraffic.com and have been analysed for the entire calendar year 2019. AIS (automatic identification system) is a GPS-based digital service that is mandatory for all ships above 300 gross tonnages as well as tankers and passenger ships of even smaller size. Thus, all ships relevant for this study are covered by AIS.

2019 has been used as reference year, as this is the most recent contingent calendar year that has not been subject to the significant temporary drops and rises in traffic volumes caused by the Covid-19 pandemic.

AIS data is analysed in a two-step approach

- First, all AIS positions belonging to the same ship on the same journey are linked to each other, i.e. geographical dots are connected creating polygon lines, so-called tracks. In each geographical grid cell, the number of tracks is counted: More lines mean more traffic and is represented with a warmer colour (yellow, red). Fewer lines mean less traffic and is represented in colder colours (dark blue, light blue). This information is aggregated and visualised in a *traffic intensity plot*.

- Second, crossing lines are drawn on top of the traffic intensity plot. Crossing lines are fictitious lines used for counting traffic. The resulting traffic counts differentiate between ship type, ship size and location where the ship track intersects with the crossing line – just to name the most important counting parameters.

3.2 Traffic intensity distribution

3.2.1 Marine Traffic Intensity mapping

Traffic intensity plot are prepared based on AIS data to visualise the traffic pattern in our area of interest. Figure 3-1 provides intensity plot considering all types of vessels. Further, intensity maps for separate vessel types are also prepared and are illustrated in Figure 3-2.

The observations confirmed that:

- The offshore wind farm construction within Zone G and Zone E (at least partially) will be in potential direct conflict with an international traffic route (ships travelling to Colombo and those circumventing Sri Lanka), having significant vessel density. This clearly requires a closer implementation of strategies to de-conflict this competing usage. A well-considered and designed, Traffic Separation Scheme (TSS) could be one of the alternatives to achieve the objective of mutual co-existence for both the competitive users (offshore wind development and marine traffic) of this important sea space.

- For rest of the OFW areas, the traffic seems to be modest.

- The OWF areas have reasonably high fishing vessel traffic, which reconfirmed the observations during rough screening that these areas support high level of fishing activities.

- No clear patten of commercial shipping traffic route between Tuticorin Port and Male (towards southwest, perpendicular to international shipping route), passing through OWF zone was observed.

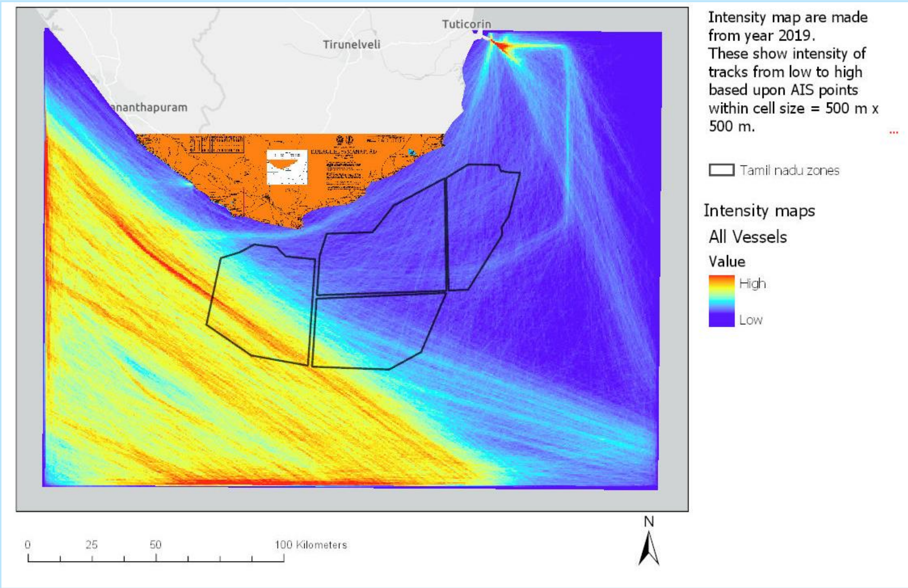
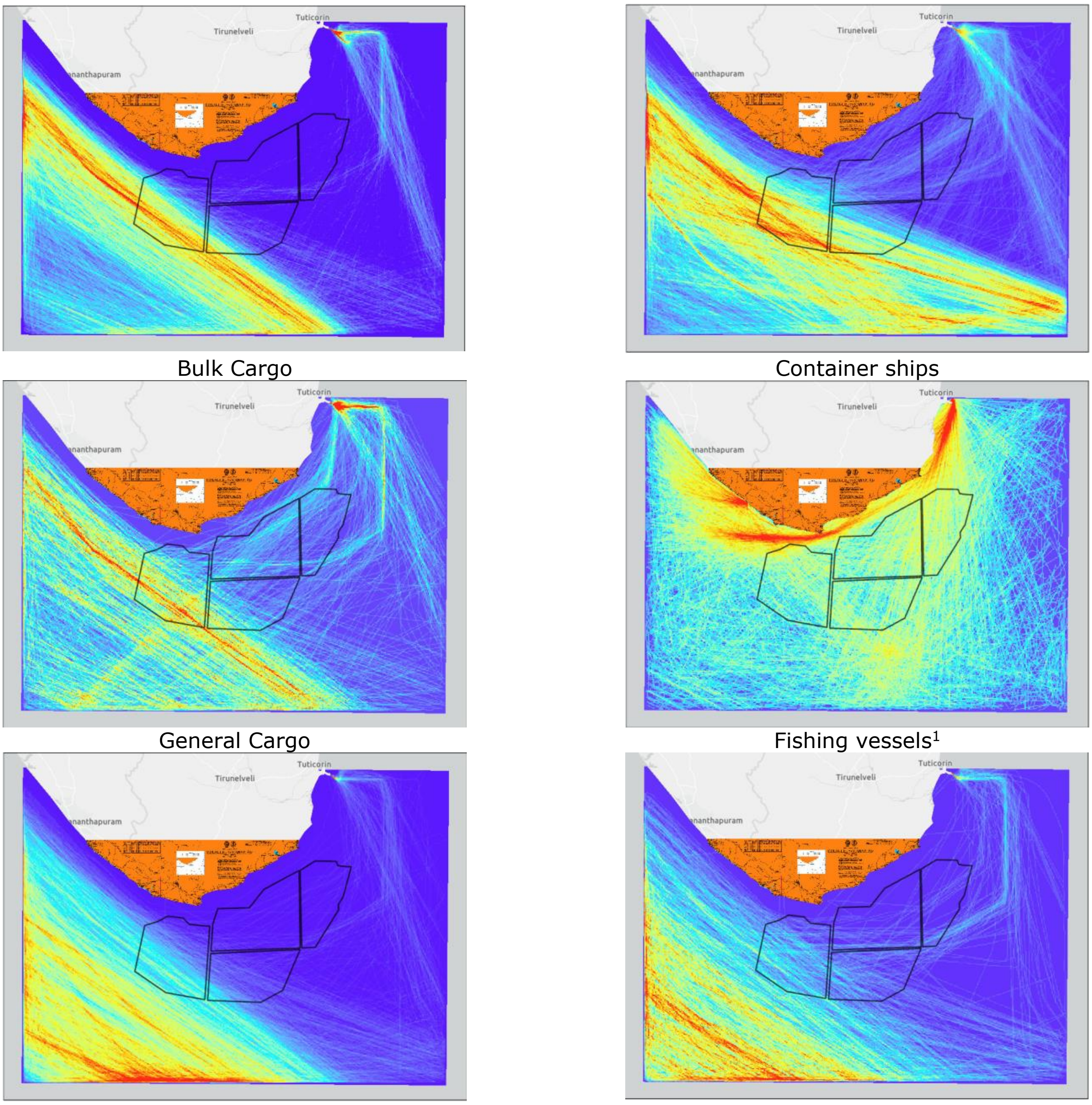


Figure 3-1 Traffic intensity map around OWF zones – all vessels (COWI)



Bulk Cargo | Container ships

General Cargo | Fishing vessels[1]

Tanker -Oil | Tanker – Gas

Figure 3-2 :Traffic intensity maps for different ship types (COWI)

[1] fishing vessel density presented in this map could be an underestimation of actual situation as a vast majority of Indian fishing fleet may not carry AIS.

3.3 Traffic counts and crossline analysis

Traffic counts and crossline analysis aims at identifying shipping traffic volume passing through the specified "crossline" The crossing lines used for counting the marine traffic in the area are displayed in Figure 3-3.

- Crossline "A" captures the traffic volume to the north close to Tuticorin Port.
- Crossline "C", captures the traffic volume close to the shoreline, outside Zone B.
- Crossline "D", to understand the traffic volume distribution within the zone B, travelling in Northeast – southwest direction.
- Crossline "E", to understand the traffic volume distribution within apparently high intensity international marine transport corridor going towards Sri Lanka and Strait of Malacca (circumventing Sri Lanka); and
- Crossline "F" capture the traffic volume towards port of Columbo

The resulting number of ship passages are presented in. In addition, the situation along crossing line E is represented by a histogram in Figure 3-4.

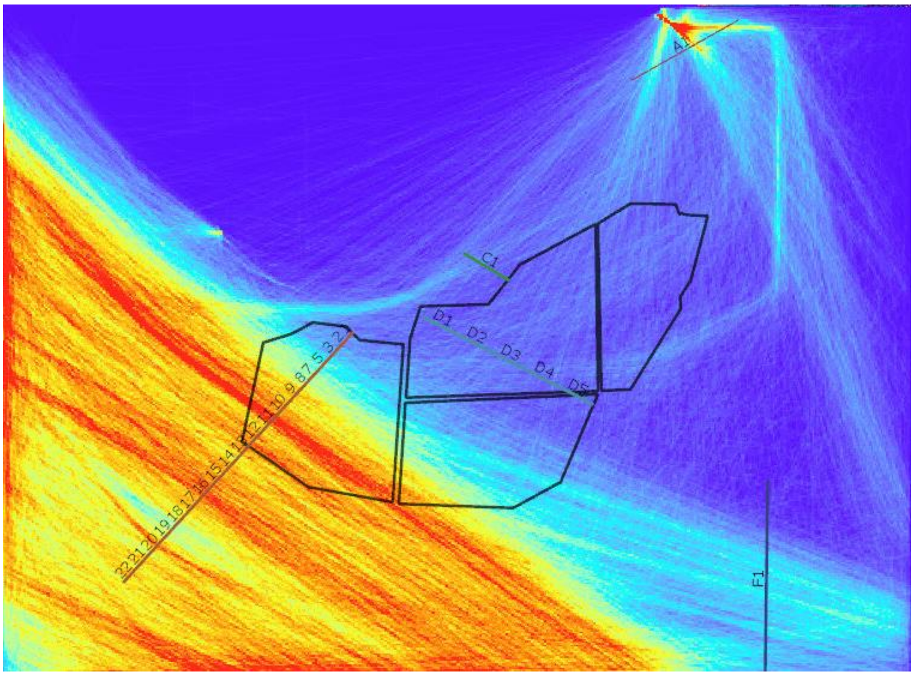


Figure 3-3 Location of the crossing lines (COWI)

Table 3-1 Traffic across the crossing lines (entire year 2019)

Crossing Line		Ship Type											
Line	**Segment**	**Bulk**	**Container**	**Fishing**	**General cargo**	**Other**	**Passenger**	**Pleasure**	**Ro-Ro**	**Tanker gas**	**Tanker oil**	**Sum**	
A	**1**	800	1,176	1,061	561	334		28	6	118	217	**4,301**	**4,301**
B	**1**		24	150	3	12		1				**190**	**2,349**
B	**2**	3	20	162	12	22		5			1	**225**	
B	**3**	10	10	169	34	57		19		2	1	**302**	
B	**4**	4	7	131	115	47		2		1	1	**308**	
B	**5**	12	16	119	112	24			1	2		**286**	
B	**6**	8	25	102	16	25			1	1	4	**182**	
B	**7**	32	46	59	37	25		1		3	14	**217**	
B	**8**	35	99	60	22	18			1	13	14	**262**	
B	**9**	83	192	37	22	9			1	7	26	**377**	
C	**1**	11	46	342	33	69		6		1	1	**509**	**509**
D	**1**	16	54	71	33	59		5	2	5	6	**251**	**1,657**
D	**2**	23	103	86	163	52		16		5	5	**453**	
D	**3**	45	70	112	98	34				11	10	**380**	
D	**4**	36	72	103	44	13			1	12	9	**290**	
D	**5**	29	19	128	12	22		2		49	22	**283**	
E	**1**	11	16	16	9	12		1	1	4	3	**73**	**21,480**
E	**2**	16	18	21	7	13	2		1	6	9	**93**	
E	**3**	9	35	28	9	9	1		1	4	6	**102**	
E	**4**	32	38	21	6	14			1	3	18	**133**	
E	**5**	30	72	20	17	13	4		1	8	26	**191**	
E	**6**	68	70	26	21	10	8		1	17	38	**259**	
E	**7**	71	114	24	17	5	4		1	20	38	**294**	
E	**8**	299	313	54	64	43	3	3	2	45	161	**987**	
E	**9**	418	370	43	94	30	6		12	76	248	**1,297**	
E	**10**	476	408	36	100	31	15		16	79	361	**1,522**	
E	**11**	595	431	21	139	34	10	2	28	85	382	**1,727**	
E	**12**	438	442	29	84	29	5	2	47	65	324	**1,465**	
E	**13**	384	401	20	57	23	4	2	42	89	431	**1,453**	
E	**14**	338	241	23	62	24		1	31	103	477	**1,300**	
E	**15**	341	306	22	54	25	1		45	108	540	**1,442**	
E	**16**	335	308	24	84	40		2	51	138	671	**1,653**	
E	**17**	243	242	20	46	18			42	230	652	**1,493**	
E	**18**	182	180	17	34	21	1	1	32	161	475	**1,104**	
E	**19**	156	130	19	28	16			49	104	470	**972**	
E	**20**	188	207	32	40	16		1	36	146	674	**1,340**	
E	**21**	153	193	24	44	19			26	205	596	**1,260**	
E	**22**	152	194	24	41	11			38	256	604	**1,320**	
F	**1**	482	2,544	131	88	69	51	5	28	209	434	**4,041**	**4,041**
Sum		**6,564**	**9,252**	**3,587**	**2,462**	**1,347**	**115**	**105**	**545**	**2,391**	**7,969**	**34,337**	**34,337**

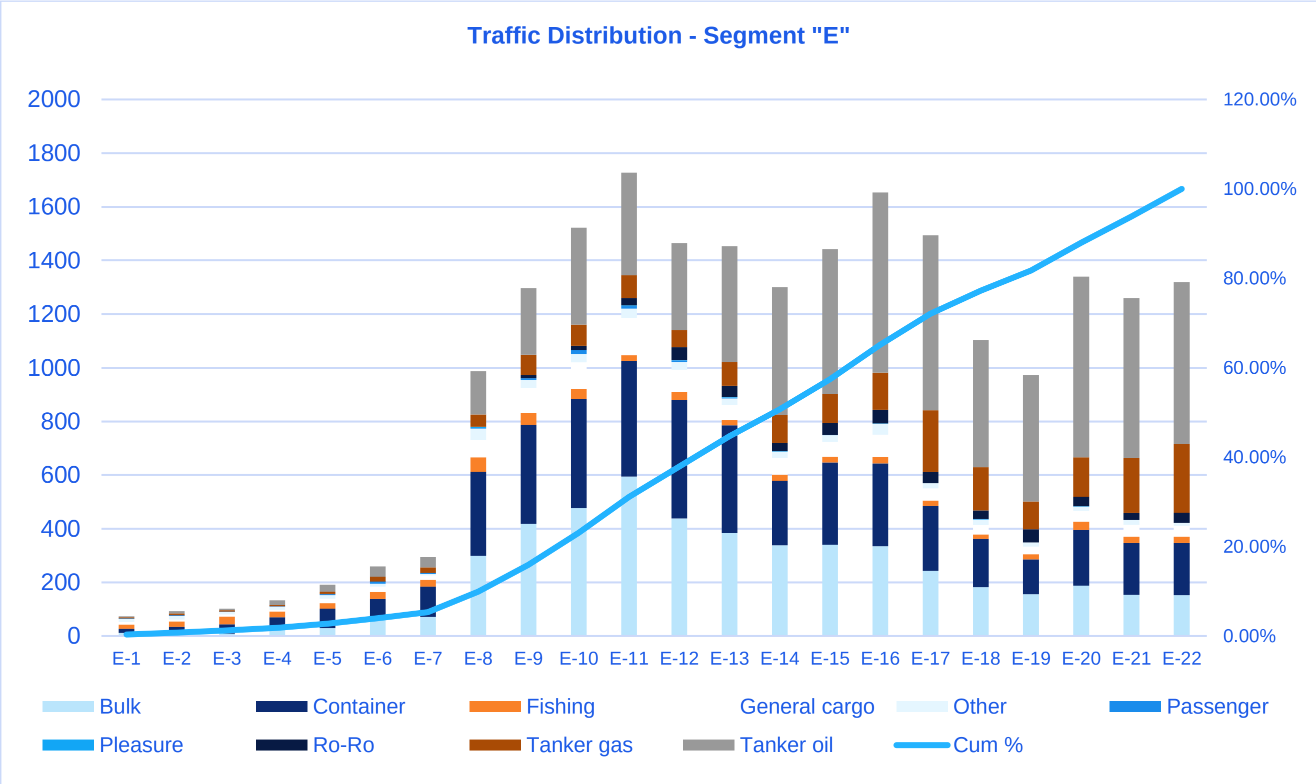


Figure 3-4 Traffic across crossing line E, illustrated as a histogram

4. Safe distances and navigation corridor

4.1 National guidance in the Netherlands

The Dutch Shipping Advisory Board North Sea and the Ministry of Transport of the Netherlands have compiled a set of international rules into an overview and interpretation document (Ministry of Transport for the Netherlands, 2013) based on

- General Provisions on Ships' Routeing of the International Maritime Organization (GPSR), 1974
- United Nations Convention on the Law of the Sea (UNCLOS)
- International Regulations for Preventing Collisions at Sea (COLREGS), 1972

The overview document shows that the required safety distance between a traffic lane border and the nearest turbine is 6 ship lengths plus 500 meters, which is width of the safety zone around the OWF. This distance applies on the port side of a designated shipping lane, e.g. one of the directional lanes of a traffic separation scheme (TSS). On the starboard side, an additional 0.3 nautical miles (556 meters) needs to be applied. For a maximum ship length of 400 meters, this corresponds to 2,900 meters safety distance between the port boarder of the traffic lane and the nearest turbine as well as approx. 3,500 meters between the starboard boarder and the nearest turbine.

In addition to the above-mentioned international rules, the overview documents includes the results of a study by Maritime Institute Netherlands (MARIN) regarding the width of traffic lanes:

- <4,400 vessels per year: Minimum lane width = 4 times ship length
- 4,400-18,000 vessels per year: Minimum lane width = 6 times ship length
- >18,000 vessels per year: Minimum lane width = 8 times ship length

For a maximum ship length of 400 meters, these three categories correspond to 1,600, 2,400 and 3,200 meters lane width, respectively.

Therefore the minimum distance between WTGs on either side of a design shipping lane would be the lane defined above plus the safety border between the lane border and the WTG on both sides as defined previously.

4.2 National guidance in the United Kingdom

Marine Guidance Note MGN 371 (Maritime and Coastguard Authority, 2008) assesses the risk level associated with different safety distances between the edge of a traffic route and the nearest turbine, see Figure 4-1.

In general terms, a very low risk will always be acceptable, and a very high risk will always be intolerable. In case of low, medium or high risk, the ALARP principle applies, i.e. possible risk-reduction options need to be implemented provided that they are proportionate (reasonable balance between cost and benefit).

Distance in nautical miles (nm) and metres (m) of Turbine Boundary from Shipping Route	Factors	Risk	Tolerability
< 0.25nm (500m)	500m inter-turbine spacing = small craft only recommended	VERY HIGH	INTOLERABLE
0.25nm (500m)	X band radar interference	VERY HIGH	
0.45nm (800m)	Vessels may generate multiple echoes on shore based radars	VERY HIGH	
0.5nm (926m)	Mariners' high traffic density domain	HIGH	TOLERABLE IF ALARP (As Low As Reasonably Practicable)* * Descriptions of ALARP can be found in: a) Great Britain Health and Safety Executive (2001) Reducing risks protecting people b) IMO (2002) MSC Circ. 1023 dated 5th April 2002 Formal Safety Assessment c) IMO (2007) MSC 83-21- INF2 Consolidated guidelines for Formal Safety Assessment
0.8nm (1481m)	Mariners' ship domain	HIGH	
1 nm (1852m)	Minimum distance to parallel boundary of TSS	MEDIUM	
1.5nm (2778m)	S band radar interference ARPA affected	MEDIUM	
2 nm (3704m)	Compliance with COLREGS becomes less challenging	MEDIUM	
>2nm > (3704m)	But not near TSS	LOW	
3.5nm (6482m)	Minimum separation distance between turbines opposite sides of a route	LOW	
5nm (9260m)	Adjacent wind farm introduces cumulative effect Distance from TSS entry/exit	VERY LOW	BROADLY ACCEPTABLE
10nm (18520m)	No other wind farms	VERY LOW	

Figure 4-1 Risk associated with different safety distances according to MGN 317 (Maritime and Coastguard Authority, 2008)

Unlike a traffic lane, a traffic route does not have a clearly defined border. Instead, the borders of a traffic route are defined as the confines encompassing 90 % of the traffic on the route, see Figure 4-2. In other words, 5 % of the traffic is sailing beyond the port border and 5 % is sailing beyond the starboard border.

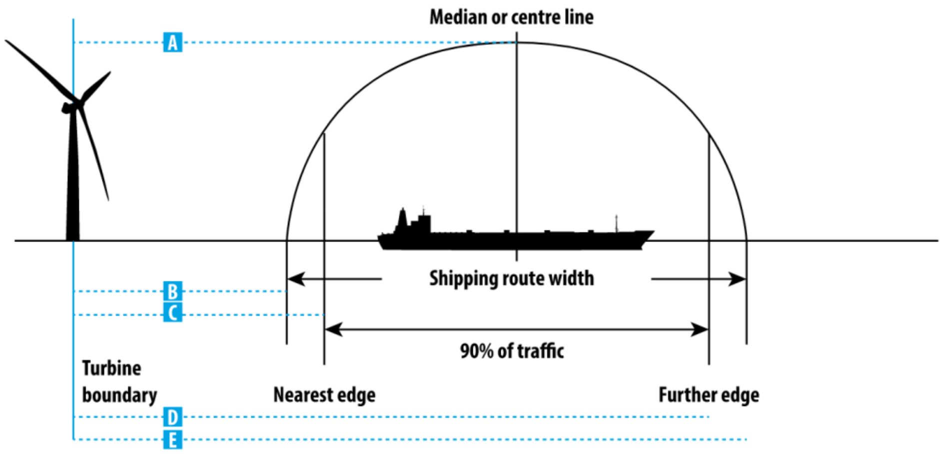


Figure 4-2 Definition of route borders according to MGN 317 (Maritime and Coastguard Authority, 2008)

4.3 Choice of corridor width in Germany

The Spatial Development Plan 2020 for the German North and Baltic Sea (BSH, 2020) designates OWF areas as well as navigation corridors. It should be noted that all navigation corridors (areas prioritised) have a consistent minimum width of 2 km (corridor 4 to 9 in Figure 4-3). When considering the area retained for navigation, the minimum width is consistently 6 km. A safety zone of 0.5 km around the OWF areas needs to be added on each side of the corridor.

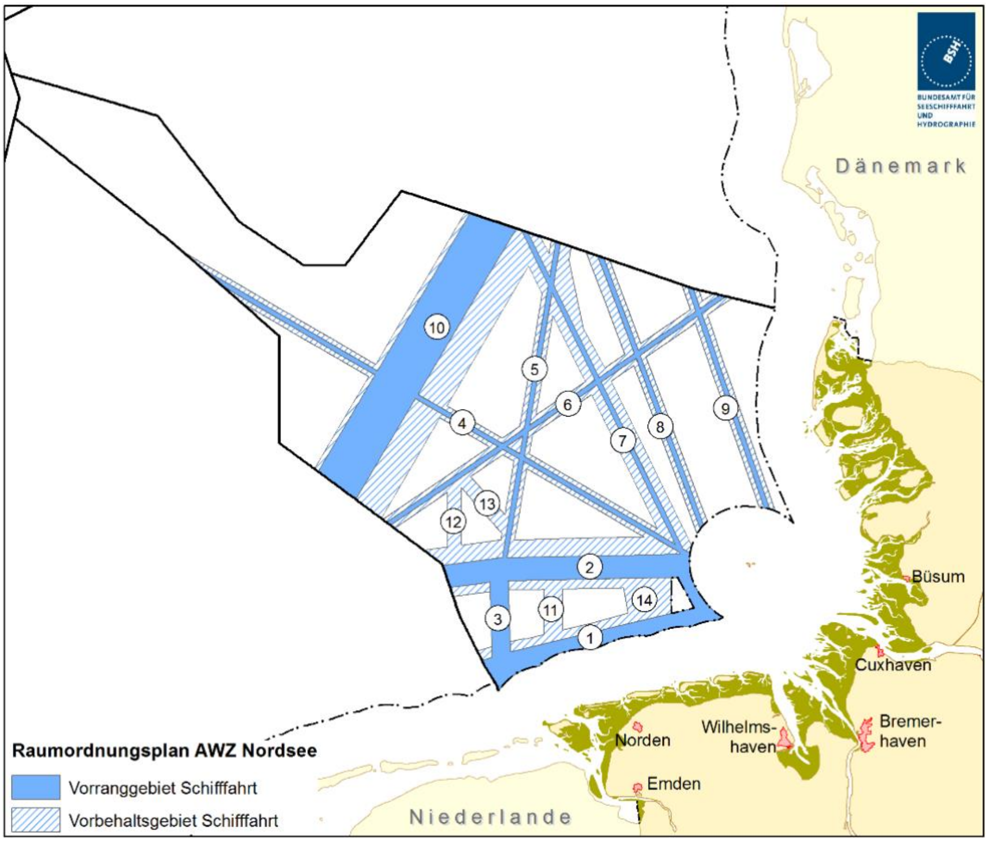


Figure 4-3 Areas prioritised for navigation (solid blue) and areas retained for navigation (hatched blue) in the German North Sea (BSH, 2020)

4.4 Observed and assumed behaviour in Denmark

In the risk assessment of Kriegers Flak OWF (DNV, 2015), it has been estimated that ship traffic will typically keep a distance of 2,500 m on average (i.e. from centre of route) to the nearest turbine if they are forced to go around an OWF. The assessment was based on the distance that RoRo ferries keep to each other when passing each other on the same route. It should be noted that the affected route passing the OWF area at the west has relatively little traffic volume (7,000 ships per year).

Moreover, a pre-post analysis of the traffic pattern at the Horns Rev 3 OFW has been carried out (COWI, 2019). Traffic relocated by the presence of the new wind turbines passed the easternmost turbine at a mean distance of 2,400 m. This direct observation confirms the estimate from the Kriegers Flak assessment. The standard deviation relative to the centre of the route is measured as 600 m. Also here, the traffic volume of the relocated route is relatively moderate (1,500 ships per year).

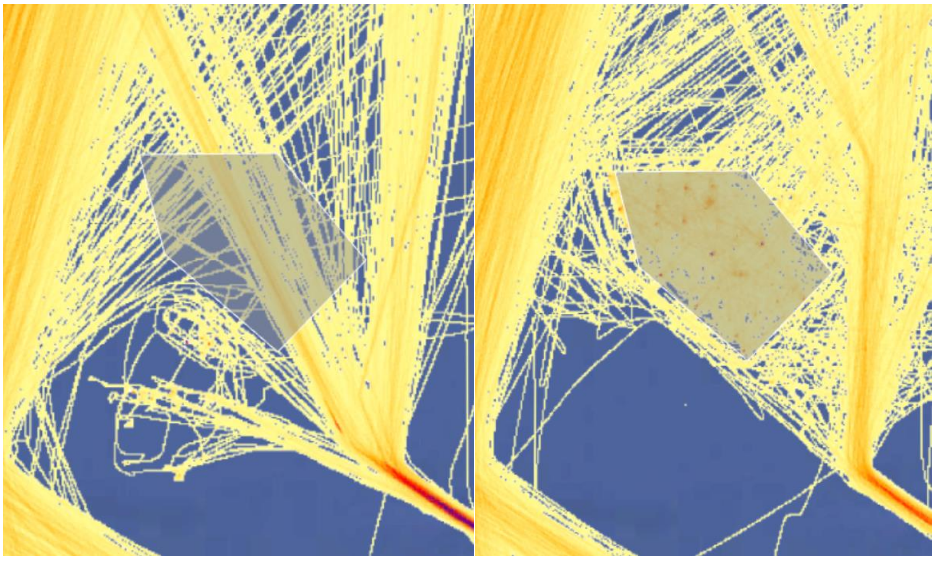


Figure 4-4 Traffic across the Horns Rev 3 OWF area before construction (left) and after construction (right) (COWI, 2019)

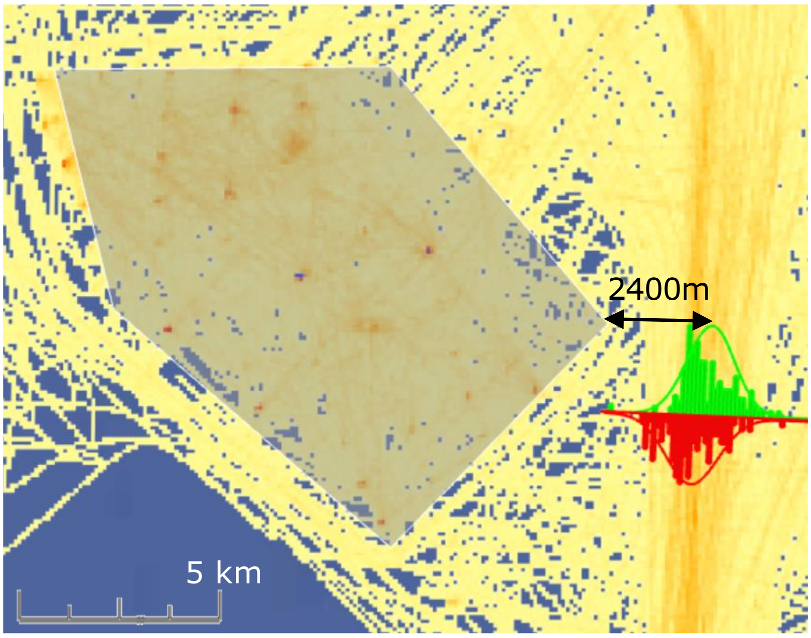


Figure 4-5 Actual distance of ships passing the easternmost turbine (exactly in the corner of the OWF area) at Horns Rev 3 OWF after construction (green = north-going, red = south-going) (COWI, 2019)

4.5 Considerations on safe distance to outer OWF boundary

The Danish experience shows that ships will naturally keep an average distance of 2,400-2,500 m to the nearest turbine on a route with a moderate traffic volume. A standard deviation of 600 m implies that 90 % of the traffic would be sailing within a band of 2,000 m width, i.e. at a distance of 1,400 (closest edge) to 3,400m (furthest edge) from the nearest turbine. The 1,400 m are in fine agreement with a mariner's ship domain (buffer zone around the ship kept by mariners) described in the UK guidance.

However, if traffic is more intense – as is the case at the southwestern boundary of the Tamil Nadu OFW area – it will not be possible to sail safely at such a close distance (1,400 m) to the OWF. This is presumably also the reason why the UK guidance indicates the risk as being "high" at such a distance.

If the OWF is built as planned in its full extent towards the southwest and if no other measures are taken (such as TSS, see next section), some of the ships will likely concentrate at such a close distance, creating a dense and potentially unsafe traffic situation.

According to the UK guidance, a safe distance would be somewhere between 2 nautical miles (3.75 km, low risk) and 5 nautical miles (9.25 km, very low risk) from the closest edge of the route.

4.6 Considerations on corridor width inside the OWF area

The number of ships passing the OWF area in north-south direction is moderate (1,650 ships per year). Thus, the minimum route width used in the German North Sea, i.e. 6 km plus 0.5 km safety zone on both sides, is likely to be sufficient. This distance will allow ships to pass each other at distance of 2 km whilst keeping a distance of 2.5 km to the nearest turbine.

5. Traffic Separation Scheme

Ship routeing systems are established in consultation with the International Maritime Organisation (IMO) in congested shipping areas of the world for safety reasons. The routeing systems consist of Traffic Separation Schemes (TSS) which include two-way routes, recommended tracks, deep water routes, precautionary areas (where ships must navigate with particular caution), and areas to be avoided for reasons of exceptional danger.

At present, COWI is not aware of any TSS been implemented in and around the southern coast of Tamil Nadu. Accordingly, it is recommended that the relevant government agencies adopt a prudent traffic separation scheme to reduce the potential conflict and navigational risk posed by offshore windfarm development to the marine traffic.

5.1 TSS for marine traffic in northwest-southeast direction

Based on the marine traffic data, significant international ship traffic is observed in northwest-southeast direction, passing through the Zone G and Zone E of Tamil Nadu. A significant portion of these zones lies within the extended economic zone and outside the territorial water of India. International Navigation has received extensive protection under United Nation Laws of the Sea (UNCLOS).

Accordingly, it is suggested that a TSS could be established in this area, respecting current routes of existing international marine traffic and their freedom of navigation.

The TSS needs to be designed to accommodate an overall traffic of approx. 22,000 ships per year, corresponding to 11,000 ships per directional lane. According to the Dutch guidance discussed in the previous section, this would require a width of 2,400 m for each of the two traffic lanes. In reality, the traffic at question is spread over at least 50 km in width. Thus, traffic lanes significantly wider than 2,400 m are easily feasible and likely to be the solution of choice.

5.2 TSS for marine traffic in northeast-southwest direction

Traffic passing the area in north-eastern and south-western direction is comparatively moderate:

- Approx. 500 vessels per year are sailing close to the coast northwest of the OFW area. This corresponds to 1½ vessels per day.

- Approx. 1,650 vessels per year are sailing through the OWF area. This corresponds to 5 vessels per day spread out over a width of 50 km.

The main purpose of a TSS is avoiding crowded and unclear situations potentially leading up to collisions. With the above traffic numbers, this precondition is not met, although collisions of course can occur under any circumstances. It should also be noted that the risk of ship-ship collisions is a square function of the number of vessel passages. Thus, when traffic across crossing line D is 10 times smaller than across crossing line E (main route in the area) under otherwise similar conditions, the risk of ship-ship collisions is in fact 100 times lower than on the main route.

Thus, there is no apparent need for a TSS organising the northeast- and southwest-bound traffic.

6. Conclusion and next steps

The marine traffic analysis concluded that, significantly large international marine traffic passing through the Zone G and Zone E is in potential conflict with offshore wind farm development in these zones. Therefore, it should be considered to establish a TSS in these areas in relation to the Northwest – Southeast direction, for mutual coexistence, with an objective of harvesting maximum possible offshore wind potential at the same time reducing navigational risks as well as avoiding disproportionate detours and traffic disturbances.

6.1 Diversion of marine traffic passing through the OWF in Northeast – Southwest direction.

Considering the traffic volume passing through the OWF zones in Northeast – Southwest direction, it was concluded that, a Traffic Separation Scheme is not required. This implies that normal navigation channels without separate directional lanes will be sufficient. These channels can either be placed inside the OWF area or adjacent to the OWF area. As an example, the existing shipping traffic could be diverted outside the zones to maximise the offshore wind development, but this decision is dependent on national priorities and a trade-off between offshore wind production yield and prolonged travel time (and CO_2 production) of the ships running in NE – SW direction.

6.2 Next steps

The overall objective of Marine Spatial Planning is to address spatial conflicts amongst various stakeholders and allow mutual coexistence of various interest groups. To attain this objective, it is 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 Tamil Nadu. 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 separation schemes. The feedback obtained will further inform the MSP process.

Appendix D:

Technical Note on Electrical Systems in Tamil Nadu

21 September 2022

Centre of Excellence
for Offshore Wind and Renewable Energy

Table of Contents

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. This 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 of the assignment is to support Ministry of New and Renewable Energy (MNRE) in their work for the implementation of 30 GW offshore wind by 2030. As a part of this initiative, DEA is assisting the Government of India in conducting a Marine Spatial Planning (MSP) for potential areas for offshore wind development around the southern cost of Tamil Nadu.

The main objective of the MSP for Tamil Nadu is to notify the most suitable zones for deployment of offshore wind in India in Tamil Nadu in accordance with the renewable policy and nationwide target of 30 GW offshore wind by 2030.

The electrical power systems network is a critical component of renewable energy planning and therefore, it is important to understand the current grid networks and planned initiatives, to assess the opportunities and bottlenecks in relation to integration of variable renewable power from offshore wind.

Accordingly, this technical note provides current understanding of grid networks in Tamil Nadu in context of the candidate OFW sites and presents the pertinent information needed for grid network planning by the relevant stakeholders to allow future integration of offshore wind to the national / regional grids.

2. Overview of OWF Area and power generation capacities

2.1 Marine Spatial Planning

To ensure the best possible use of the marine space in an efficient, safe and sustainable way the National Institute of Wind Energy (NIWE) together with the Danish Energy Agency (DEA) will be carrying out a Maritime Spatial Planning project in the states of Tamil Nadu. The Maritime Spatial Planning project will build on the existing work carried out in the FOWIND and FOWPI projects to refine and make further recommendations supporting a clear and transparent future planning and collaborative balance of interests, which will encourage investments in offshore wind.

The MSP focuses on the Tamil Nadu offshore potential and presents the importance of marine spatial planning in building up a pipeline of projects. The potential zones for offshore wind development, identified in FOWIND study were further refined based on the following considerations:

- Available wind potential
- Environmental considerations
- Social consideration and co-existence with completing users of marine space such as marine traffic, oil & gas industry, fishing industry, tourism and cultural heritage, etc.
- Availability of supporting infrastructure including grid network and ports.

2.2 OWF areas and conceptual plan

The site screening process identified and have evaluated the key constraints and potential conflicts with competing users, that offshore wind farm development in TN Zone B, G, E & D may present. Based on preliminary evaluations of these potential conflicts, a shortlisted site (~ 3,600 km²) is identified for priority development of offshore wind farms in Tamil Nadu.

The key consideration being:

- The individual plot (may be considered as individual windfarms) size around ~ 200 Km². These individual plots could support windfarms of size ranging from 1 GW – 1.5 GW, depending on turbine density adopted by the project developers.
- An electrical infrastructure corridor of approx. 1 km width is provided, to be utilised for laying electrical export main cables. This corridor will also allow unhindered access to each plot for O&M vessels.
- Electrical infrastructure corridors are oriented towards the coastline for the shortest distance to the coastline, although slightly included to provide ease of access to the construction and operational vessels.

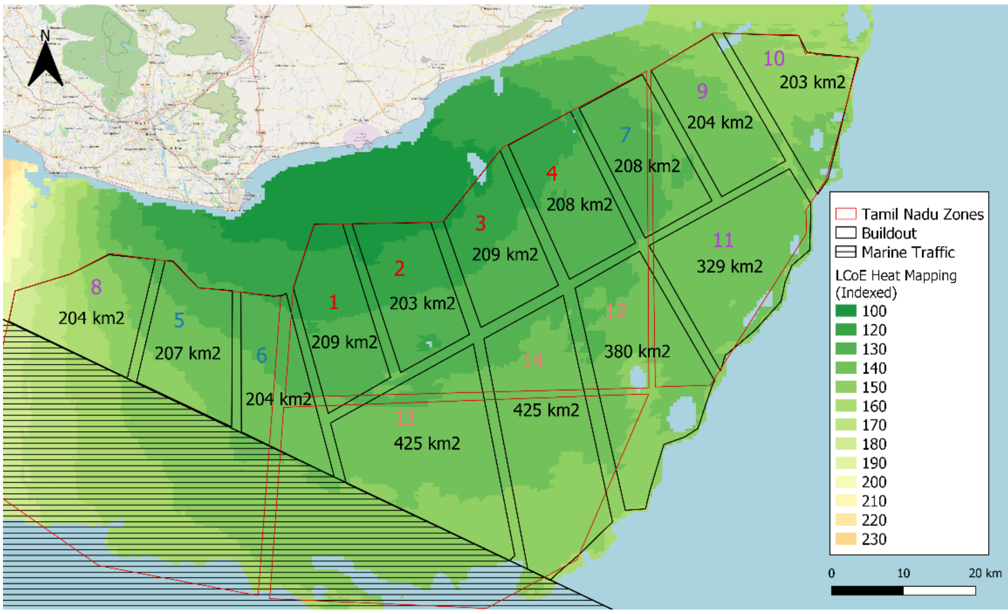


Figure 2.1 - Buildout Plan for Tamil Nadu Sites

2.3 Potential power generation

Based on the assessment carried out under MSP, it is estimated a potential of ~ 10 to 25 GW (depending on turbine density and other considerations) of offshore wind power generation within the identified site. It was further concluded that:

- It would be prudent to consider a buildout plan, starting with 1.0 GW and eventually 1.5 GW of individual offshore wind projects.
- Buildout rate needs to be aligned with existing grid capacity and planning for strengthening the backbone transmission infrastructure.
- The ranking of sites / plots to considering the grid connection points (PoC) and the layout may be reconfigured to allow minimizing distance from OWF to the PoC.

Accordingly, it is imperative that the Grid networks has the capacity for an efficient transfer / offtake of this significant volume of renewable energy consumers.

2.3.1 Development time frame

The development timeframe for offshore wind projects is dependent on various factors including but not limited to the following:

- MNRE's procurement timeline of OWF projects
- Regulatory approvals and policy initiatives to support OWF in India
- Preparedness of supply chain and logistical infrastructure to support OWF development; and
- Global supply chain considerations

Assuming, the MNRE commence issuing the auction notices in 2022, early OWF projects (of 1-2 GW, depending on MNRE strategy) would need connection to the Grid in year 2027-2028 as illustrated in Figure 2.2.

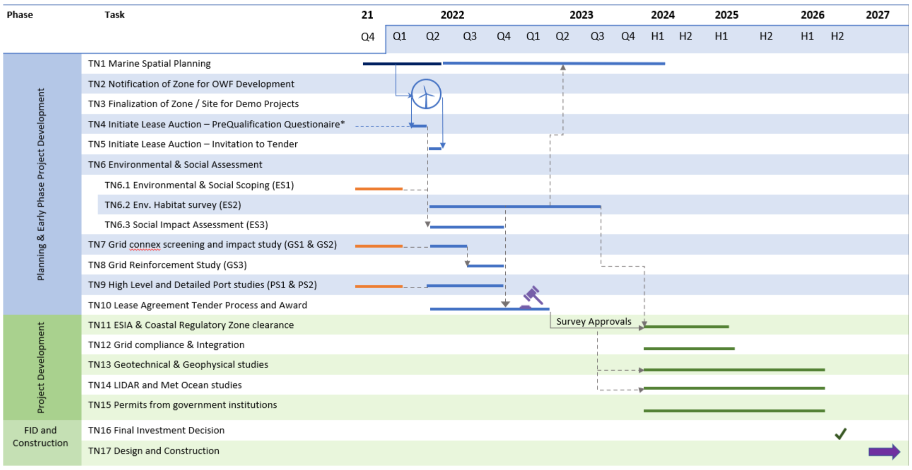


Figure 2.2 - Approximate timeline for early OWF project(s)

3. National Grid Overview

India, as of July 2021 has achieved a total installed generation capacity of around 384.9 GW. The country is the world's third largest producer of electricity. In the current year 2021-22, while the annual target is 1356 BU, until August 31st, 2021, 562.52 BU had been generated since April 1st, 2021. The gross per capita electricity consumption was 1,208 kWh[1,2].

The generation happens at varying voltages depending on the size and type of the generating plants but generally one could consider 11 KV as the generation voltage connecting to the grid at 11 KV to 765 KV. The electricity grid operates at 50 Hz and in case of large conventional power plants (>100 MW) grid connection happens at 220 KV to 765 KV while in case of Renewable Energy (RE) plants, which are individually of small capacities, the generation voltage is 400 V (for Solar) or 690 V (for wind), which is stepped up to 33 KV, pooled and connected to the grid at 132/ 220/230 KV. Very early RE plants have connected to the grid even at 11 KV. The long-distance transmission backbone of the electricity grid in India can be considered to exist at 400 KV/ 765 KV/ (500 KV-800 KV HVDC). These voltages enable inter-regional or inter-state transmission of power. The main Intra-State transmission system is at 220/230/400 KV. The power distribution system that carries the power to the end-user is of 33 KV/ 11 KV/LT.

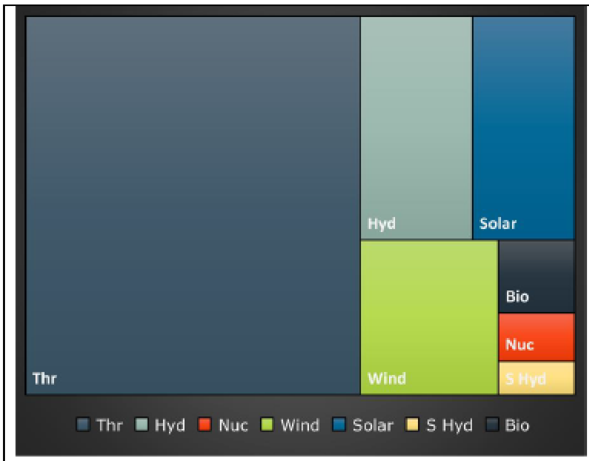
3.1 Generation

Of the 384.24 GW generating capacity[3], 60.6% (234.25 GW) is thermal or fossil-fuel based generation. All non-large hydro Renewable Energy based capacity is nearly 100 GW or 25% of the total capacity and all non-fossil-fuel generation capacity not including nuclear but including large hydro is 145.23 GW accounting for 37.6%. (See Figure 3.1).

[1] Source: CEA

[2] National Power Portal (https://npp.gov.in/publishedReports)

[3] The National Portal shows 386.88GW as of July 31, 2021 as the total installed capacity and 98.88 GW of RE installed capacity



Type	Cap (GW)	%
Thermal	234.25	60.6%
Hydro	46.32	12%
Nuclear	6.78	2%
Wind	39.49	10%
Solar	42.33	11%
S Hydro	4.79	1%
Bio	10.34	3%
Total	384.24	

Figure 3.1 - Generation mix and installed capacity break-down (GW) (2014)[4]

The Thermal Capacity breakup in GW is given below in Figure 3-2. It can be seen that coal accounts for 86% of the thermal capacity and 52% of the total capacity. Thus Indian power sector is mainly reliant on fossil fuel (FF) based generation and among FF, coal is the predominant fuel.

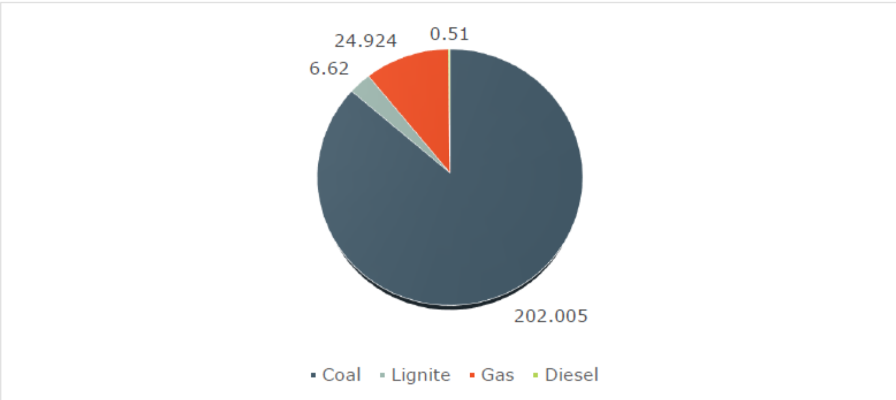


Figure 3.2 - Thermal mix and installed capacity break-down (GW) (2021)

Renewable Energy Break-up (GW) by sources is presented in Figure 3.3. Until 2020, wind energy accounted for the highest RE capacity, however, in 2021 we see emergence of solar as the highest RE component in the mix.

[4] Source: CEA

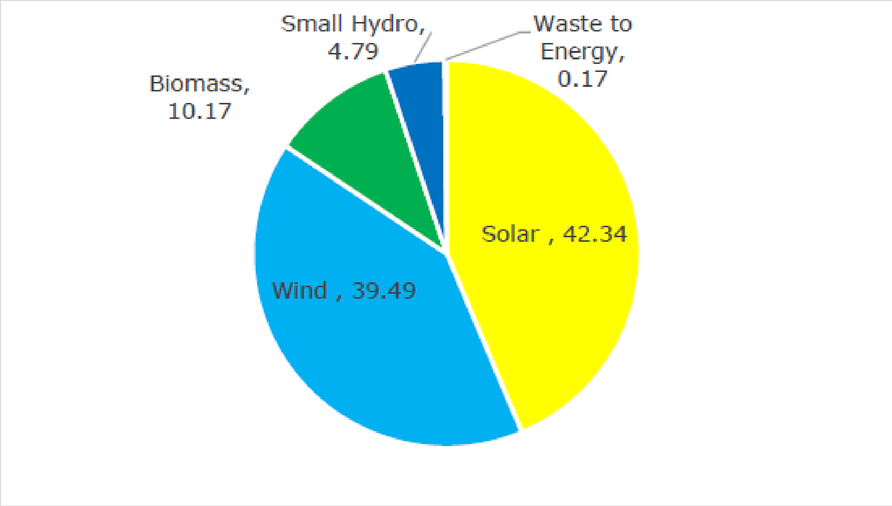


Figure 3.3 - Renewable energy break-down by sources (GW)

At 1.76% (6.78 GW) of the total generation capacity, Nuclear remains the smallest component in the generation mix.

3.2 Transmission

For operational purposes, the transmission network in India is divided into five regional grids, which were unified to operate on 50 Hz frequency in Dec 2013 after the interconnection of the southern region with rest of the grids at by means of 765 kV Raichur-Solapur transmission line.

The total transmission network of 220 KV and above in the current year (2021-22) is of the order of 443.371 CKM and the total transformation capacity at 220 KV and above is of the order of 103.686 MVA. The interstate transmission system is managed by the Central Transmission Utility (CTU), which is the Power Grid Corporation of India Limited (Powergrid). Powergrid owns and operates about 161.790 ckt kms of transmission lines at 800/765 kV, 400 kV, 220 kV & 132 kV EHVAC & +500 kV HVDC levels and 248 substations. The transformation capacity managed by Powergrid is of the order of 396.825 MVA. The States have their own transmission networks, which are integrated to the national grid.

As far as RE is concerned, it is not evenly distributed all over the country and there are high potential areas, particularly in case of onshore wind. This is also the case for offshore wind and large-scale utilization of offshore wind also requires a sound connectivity between the regions / load centres. The existing transmission network is being upgraded and strengthened by PowerGrid to establish inter-State and inter-regional links.

Major developments that have taken place in strengthening the electricity grid over the last two decades are listed in Table 3-1 below. This list also enables us to gauge the total high voltage long distance transmission capacity developed in the country so far. It can be seen that major long distance 400 KV, 765 KV and HVDC lines have been commissioned over the last 2 years. Amongst these are Bipole-I (3000 MW) of ±800 kV Raigarh - Pugalur HVDC transmission line commissioned in 2021, 800 kV HVDC Raigarh (HVDC stn) - Pugalur (HVDC stn) Bipolar Link (3531 Ckm) commissioned in 2020. Irrespective of the generation source (hydro, thermal, or RE), HVDC provides efficient and cost-effective transmission of very high levels of remotely generated power over very long distances.

Table 3-1 Major Developments in Power Transmission in India (2000-2021)

Transmission in India (2000-2021) 2000	Introduction of 765 kV transmission line (initially charged at 400 kV)
2003	Western Region was interconnected to ER-NER system synchronously through 400 kV Rourkela-Raipur D/C line and thus the Central India system consisting of ER-NER-WR came into operation Bulk inter-regional HVDC transmission system (Talcher– Kolar HVDC link-2000 MW)
2006	Synchronous inter-connection of NR with ER-NER-WR system led to the formation of NEW grid (with commissioning of Muzaffarpur-Gorakhpur 400 kV D/C line, the Northern Region also got interconnected to this system making an upper India system having the NR-WR-ER-NER system
2007	NR also synchronously interconnected with WR through Agra- Gwalior 765 kV S/C line-1 operated at 400 kV level (besides interconnection of NR-ER)
2007	765 kV operation of Sipat Substation
2007	765 kV operation of 765 kV transmission lines
2014	The Southern Grid synchronously connected with rest of all-India grid in December, 2014 through S/C 765 kV Raichur- Solapur line
2016	NER directly connected with NR. The longest 6000 MW HVDC line (±800 kV) from Bishwanath Chariali in NER to Agra in NR for dispersal of power from NER to NR/WR
2017	765 kV D/c Nizamabad-Hyderabad commissioned in July'17
2017	+ 800 kV Champa-Kurukshetra HVDC Bipole-I, commissioned in Sep.'17
2017	+ 800kV Alipurduar-Agra HVDC Bipole, commissioned in Sep'17
2018	765 Jabalpur-Orai- Aligarh D/C IR System commissioned in Mar'18
2019	Srinagar-Leh Transmission System (SLTS) commissioned in Jan'19.
2020	Transmission system associated with GEC-I completed by Mar'20.
2020	Transmission system associated with Solar Ultra Mega Power Projects completed by June'20.
2020	765 kV D/C Chilkaluripeta – Cudappah line commissioned in Jan'20

2020	765 kV D/C Vemagiri – Chilakaluripeta line commissioned in Jan'20

Source: MoP

3.3 Green energy corridors

"Green Energy Transmission Corridor" is a major initiative of the government of India for evacuation & integration of the renewable energy (RE) capacities. The plan was sanctioned in 2015-2016, is being implemented by PGCIL. Under green corridor -I, eight renewable-rich states of Tamil Nadu, Rajasthan, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh, and Madhya Pradesh are interconnected with the aim to support 33 GW of Solar and Wind power. The project includes approximately 9400 ckm transmission lines and substations of a total capacity of 19000 MVA. The purpose is to evacuate 20,000 MW of large-scale renewable power and improvement of the grid in the implementing states

There has been a focus on evacuating power from the RE rich States of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, Madhya Pradesh and Tamil Nadu. The green corridor runs through these states from the very south of Tamil Nadu to Rajasthan in northwest. In order to evacuate the proposed capacity addition in these States, transmission system, both intra-state and inter-state, have been set up along with the setting up of Renewable Energy Management Centres (REMC) and the control infrastructure such as, reactive power compensation, storage systems, etc. The REMC are as follows:

1. REMC-SR (Tamil Nadu, Andhra Pradesh, Karnataka SLDCs & SRLDC).

2. REMC-WR (Gujarat, Maharashtra, Madhya Pradesh SLDCs and WRLDC),

3. REMC-NR (Rajasthan SLDC, NRLDC and NLDC)

The inter-state transmission systems assigned to Powergrid have been completed. For the state of Tamil Nadu, Intra-State Transmission system has a line target of 1068 ckm out which 906 ckm has already been constructed. Further, Inter-State Transmission system between Tirunelveli Pooling Station-Tuticorin Pooling Station 400kV 2xD/c of length 48 ckm has been completed.

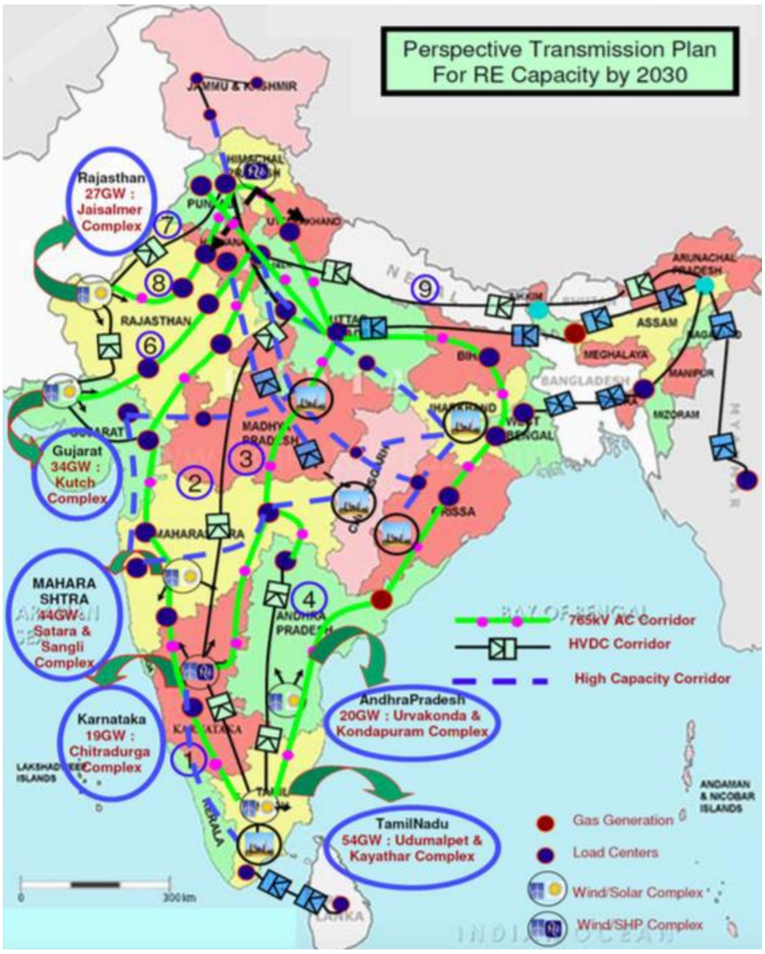


Figure 3.4 - Green energy corridor transmision plan by 2030

The list of RE projects catered to by the green corridor (inter-state connectivity) in different regions are summarised in Table 3-2. There are in addition wind and solar projects functional under State transmission system, and only around 600 MW are reported at the National Load Despatch Center (NLDC) and tracked by CEA.

Table 3-2 Regional break-down of RE projects connected to the green corridor (MW)

Region	Capacity (MW)
Northern Region	3048
Western Region*	3310.4
Southern Region	4553
Total	10911.4

* Madhya Pradesh is included in Central Region

Source: CEA

3.4 Power evacuation opportunities around OWF zones in Tamil Nadu

An ever-expanding transmission and distribution network has enabled Tamil Nadu to tap the existing wind and solar sites and generate significant amount of power from RE sources. At present, grid evacuation capacity and transmission infrastructure allow Tamil Nadu to carry the power generated from high wind areas to load centres.

The regional backbone power grid (400kV and above) is shown below where also preliminary connection points are indicated. It is pertinent to mention that existing 230 kV (Figure 3-5) and 110 kV substations could be potentially a viable option for grid connection of smaller OWF's. For example, a 220 kV substation (SS) can receive 2 x 500 MW export cables from "far shore OWFs" and 110 kV can receive a number of 66 kV export cables from "near shore OWF", subject to availability of balanced (unutilised) capacities at the respective substations.

Figure 3.5 - Regional Backbone national grid (400 KV and above)

Power Grid Corporation of India (PGCIL) is working towards the enhancement of the country's grid by adding more substations of 400kV, 765kV HVDC upto 1200kV HVDC. In Tamil Nadu , PGCIL has ten(10) 400kV substations. 4 substations are of 765kV of which some are currently charged at 400kV only.

A number of substations of different kV ratings are found in the coastal regions in the vicinity of proposed wind farms around the zones which are illustrated in Figure 3-6 below.

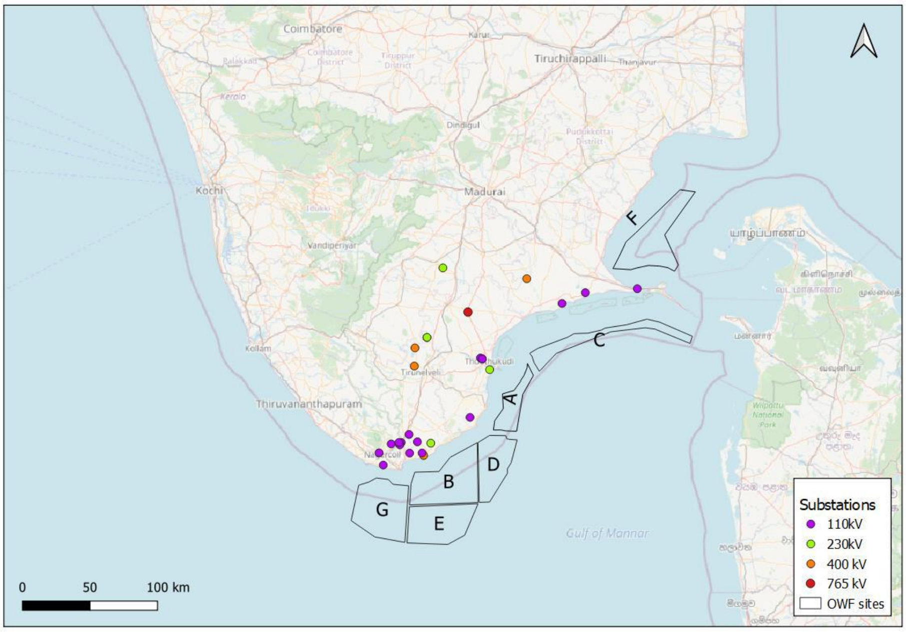


Figure 3.6 - Electrical substations in vicinity of OWF zones (COWI, 2021)

All of the above substations are located within 20 km from the boundary of the selected zones. While 230 KV substations are acceptable for early phase / projects, connections to 400 KV substations would be required for large scale development of offshore wind zones.

The closest 400 KV substation is Koodankulam substation, which is currently connected to Koodankulam Nuclear Power Plant is expected to have significant balance capacities for upgrade given the expansion plans of this Nuclear Power complex. However, this needs to be confirmed in consultations with Indian Stakeholders.

4. OWF power system requirements

The power system infrastructure requirements for offshore wind farm(s) will depend on several factors, such as:

- Installed capacity [MW] of the windfarm site
- Distance to the Point of Connection (POC) at an appointed grid substation
- Voltage level required [110kV, 230 kV or 400 kV] at PoC

The responsibility split between the OWF and the grid company is not yet fully established. A preliminary assumption is that the OWF developer will design, build and operate the transmission asset to the PoC. The regional (TRANEDCO) and / or national grid (Power Grid) operators are expected be responsible for identification / establishment of PoC and necessary reinforcements in the existing backbone transmission grid. This will undoubtably require Energy Master Planning and power system studies implemented by relevant Indian stakeholders.

The power infrastructure of offshore wind farms comprises a mix of below components:

- 66 kV array cables from the WTGs
- Offshore substation
- Export cable systems to shore
- Landfall of sea cables
- Overhead line or land cable systems
- Nearshore transformer station
- Interconnector to Grid Substation Location (OHL or UG-Cables)
- Windfarm substation close to Grid Substation
- TSO's Extension of Grid Substation
- (TSO's Reinforcement of back-bone transmission power grid)

4.1 Example offshore electrical infrastructure for 1.0 – 1.5 GW power project

In this section, the typical offshore electrical infrastructure rated between 1 to 1.5 GW is demonstrated. When we say typical, it is the project with moderate distance to shore and moderate water depth. For such an offshore wind farm, the electrical infrastructure consists of inter-array cables, an offshore substations (OSS), exporting cables, onshore substations (OnSS) and land exporting cables/OHLs. Figure 4-1 vividly demonstrate the corresponding electrical components.

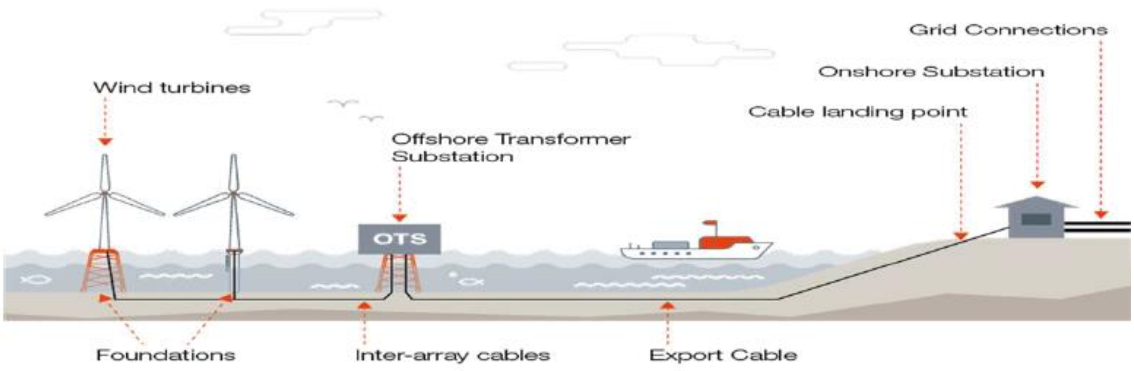


Figure 4.1 - Typical offshore wind farm infrastructure

When it is more specific to a 1 to 1.5 GW project, like the one shown in Figure 4-2, the dimensions of the electrical infrastructure become clearer. It comprises

- ONE 1/1.5 GW OSS is anticipated at the centre of the OWF site and connected with 12 IAC strings
- TWO/THREE 275 kV subsea cable circuits (export cables) to landfall, each equal to about 20-25 km
- TWO/THREE about 5 -10 km long 275 kV cable circuits (onshore export cables)
- ONE about 5 km long 275 kV double circuit OHL (onshore export OHL)
- ONE OnSS next to the Grid SS
- ONE 230 kV double circuit OHL/TWO 230 kV cable circuits (connection to the grid SS)
- TWO new 230 kV line bays in existing grid SS (existing grid SS extension)

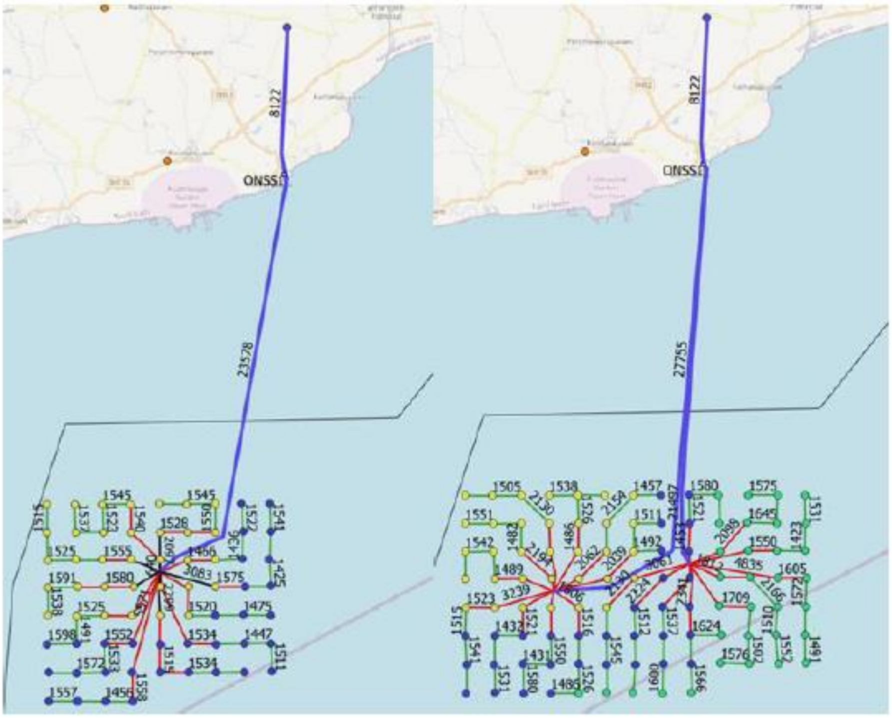


Figure 4.2 - typical 1 GW and 1.5 GW offshore wind farm layout (left: 1 GW, right: 1.5 GW)

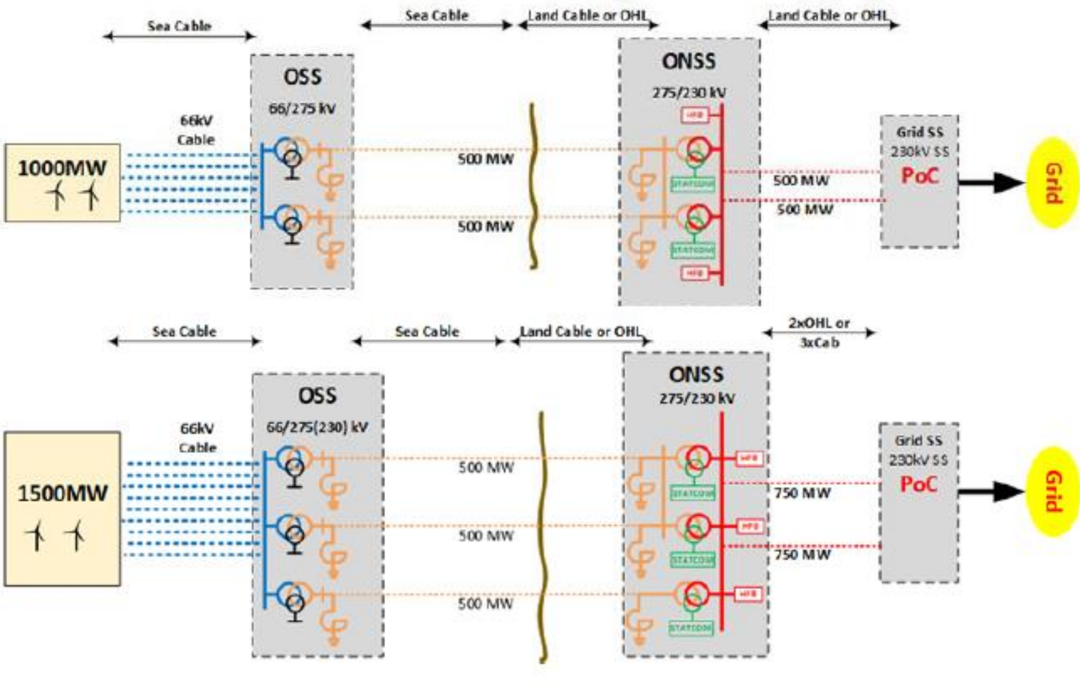


Figure 4.3 - typical 1 GW and 1.5 GW offshore wind farm electrical concept diagram (top: 1 GW, bottom:1.5 GW)

5. Discussion on TSO / Developer led model

There have been two different paths with regard to the leadership of developing offshore wind farm export system as illustrated in Figure 5-1.

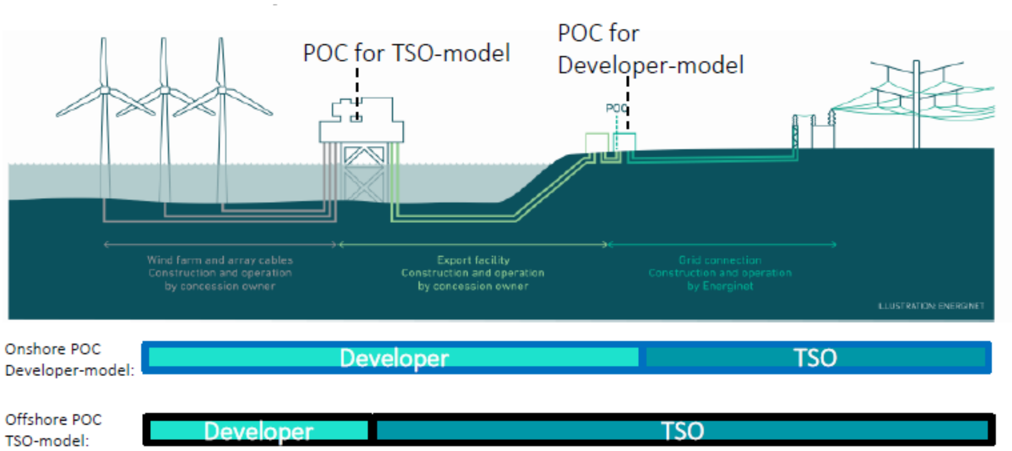


Figure 5.1 - Developer led Vs TSO led electrical system development model

One of them is the developer led export system model, which means the developer takes the ownership in planning, designing, constructing and operating the offshore substation, on/offshore export cables and onshore substation with its connection to the existing grid substation.

Many markets have adopted this model, which transfers most of the risks to the developer. With the export CAPEX and the associated development cost, the resulting total investment and LCoE go higher. However, the “stranding” risk the wind farm project becomes lower, as the developer takes the lead and owns the whole value chain. This model also tends to grow the radial connected offshore wind farms, unless the developers negotiate and carve out the development and connection plan for the long run, that the adjacent offshore wind farms should be connected onto the same substations/energy hubs, to maximise the synergy. The development model might reduce development lifecycle and for single project efficient, however requires bigger investment and potential complexity for the developer.

The other model is the TSO led export system model, and being different from the developer led model, the TSO takes the ownership in planning, designing, constructing and operating the offshore substation, on/offshore cables and onshore substation with its connection to the existing grid substation.

Compared with the developer led model, the TSO/government is able to plan for the whole offshore leasing plots in the certain area, an evacuation mechanism, a collective HVAC/HVDC offshore substation rated for multiple adjacent wind farms, even a multifunctional energy island/hub, etc. This may not be the most efficient way for a single offshore wind farm project, and there have been massive German North See grid connection delays in early 2010s, due to ”limp” TenneT export system construction. With those lessons learnt, this model should be effective in the government/policy leading countries/markets to achieve low marginal costs.

Figure 5-2 provides an overview of different government, developer and transmission system operator roles in established offshore wind markets.

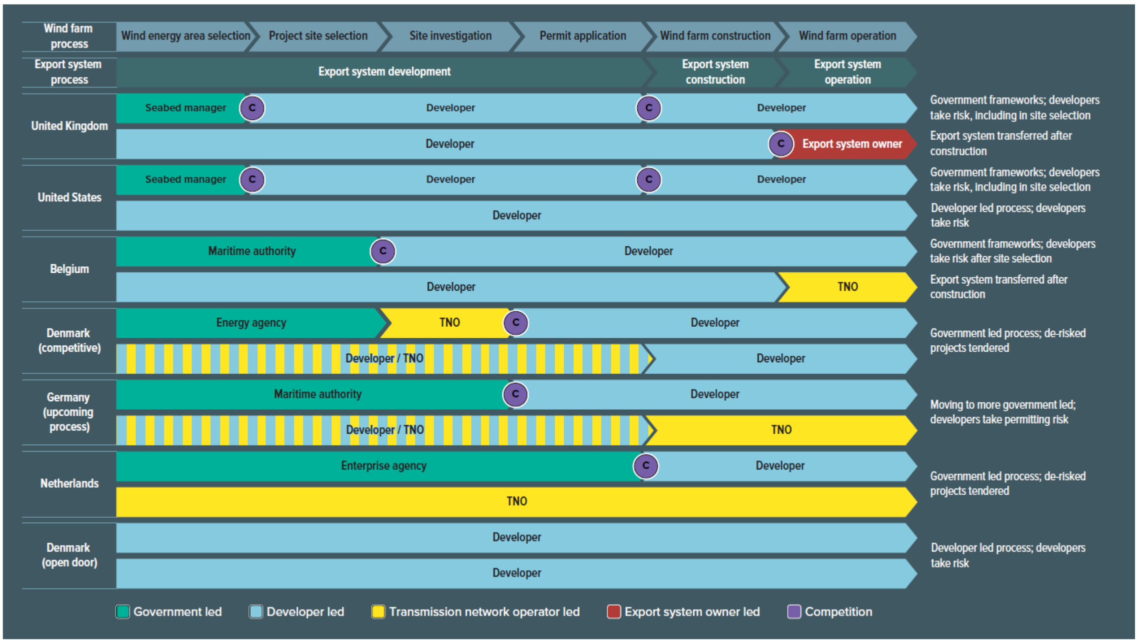


Figure 5.2 - Developer and Transmission system operation roles in global offshore wind markets (Source : WorldBank, Key factor report 2021)

6. Key questions and planning issues

A robust grid connection is necessary for offshore wind projects to be established in coastal areas south of Tamil Nadu. The current high-level assessment (based on open-source data) indicates a presence of significant backbone grid infrastructure, that would need to be further assessed and developed, to allow planning for connectivity to future offshore wind farms.

At present, the data available in public domain does not allow detailed analysis of robustness of backbone grid transmission system in the context of integration of potential OWF. Overall analysis of the backbone transmission system including balancing is essential when adding a significant amount of offshore wind. Previous studies are valuable, but up to date analyses for outbuild and support are essential. The Green Energy Corridor has paved the way, but specific analysis needs to be done for the 15-25 GW offshore wind to be added in Tamil Nadu Both national and regional considerations must be accounted for. Planning ahead provides comfort to the developers, therefore is essential that the projected OWF project generation is accounted for within the national grid planning and energy master plans.

Accordingly, the following pertinent questions are requested to be answered:

Grid connection points

- Identification of grid connection points (substations), which are the most suitable PoC considering existing (balanced capacities) and planned infrastructure considering geographical spread of OWF areas.

Landfall points

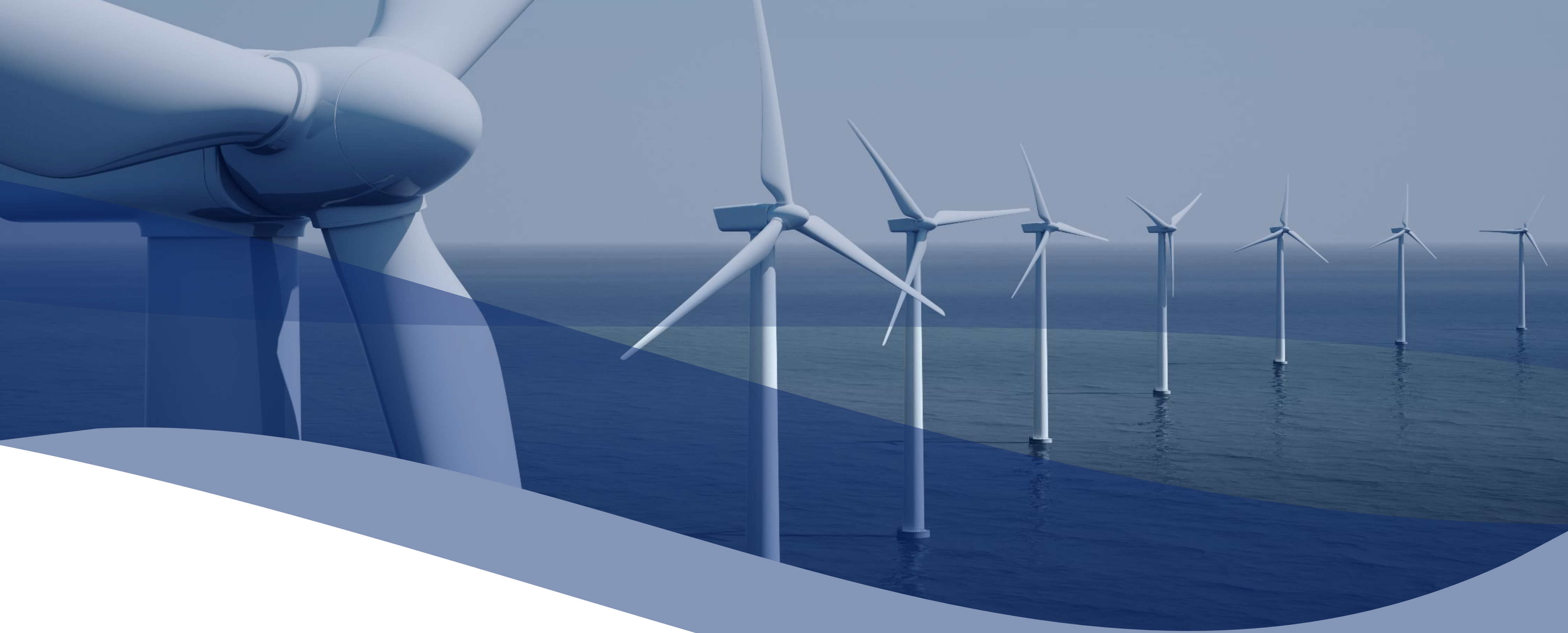
- Where would the landfall points be located?

Impact on the Grid

- Can the existing grid handle connection of offshore wind farms in Tamil Nadu?
  - What would be power system typology including the evacuation capacities spread over the time?
  - Main component specification for onshore grid substation and point of interconnection (PoC)
  - Initial load flow stimulations and short circuit assessments needed to be conducted

Grid Reinforcement Program

- What needs to be done to the PoC substation and the backbone transmission system to accommodate the planned OWF?
  - Evaluate grid reinforcement options
  - Necessary upgrade required to PoC and transmission system



Appendix E:

Overview of Engagement with Indian Stakeholders

Centre of Excellence
for Offshore Wind and Renewable Energy

Centre of Excellence
for Offshore Wind and Renewable Energy

1. Maritime Spatial Planning for offshore wind in India – Overview of engagement with Indian stakeholders

1.1 Background

The development of offshore wind and maritime spatial planning is an area which needs special attention and cooperation across various government institutions. Even though the ocean seems an open and eligible space, there are quite a lot of different interests which must be considered before engaging in planning specific projects.

To ensure the best possible use of the marine space in an efficient, safe and sustainable way it is important to have an extensive and thorough dialogue with Indian Government authorities and stakeholders. This element is perceived crucial for balancing multi-interests at sea and developing solid conclusions in relation to offshore wind planning. The overall aim is to minimize risks and uncertainties for investors and encourage long-term investments.

1.2 Current status of the stakeholder engagement

Below is provided an overview of the current status of the engagement with Indian stakeholders including a proposal for the way forward.

Stakeholder	Request	Response	Way forward
Tuticorin Port (V. O. Chidambaranar Port Trust)	Request to obtain marine shipping traffic data for Tuticorin Port sent in October 2021.	The Marine Shipping data for VOC Port for the last 3 years has been received and included in the draft MSP reporting.	Continue liaison with the Tuticorin Port – both in relation to the maritime spatial planning and challenges regarding marine traffic, but also in relation to the port study. In relation to the follow-up a note on marine traffic has been produced to be shared and initiate the discussions regarding marine traffic and co-existence with offshore wind.
Ministry of Ports, Shipping and Waterways (MoPSW)	Request to obtain marine shipping traffic data for Gujarat and Tamil Nadu areas send in October 2021, and a gentle reminder sent in December 2021.	Initially no response received, but a very constructive meeting was held in April 2022. Following the very constructive meeting, a specific note on marine traffic was share with the MoPSW.	Follow-up with the MoPSW based on the marine traffic note and analysis included to further discuss marine traffic and co-existence with offshore wind. In relation to the port study the engagement with MoPSW is also considered key as an important stakeholder.
The Central Marine Fisheries Research Institute (CMFRI)	Request to obtain fishing and aquaculture data in Tamil Nadu send in October 2021, and a gentle reminder sent in December 2021.	No response received so far – either on the initial request, the gentle reminder or the latest request from July 2022.	Follow-up with CMFRI based on the maritime spatial planning report and the specific data and details focusing on fisheries and aquaculture.

	A further request to obtain fishing and aquaculture data in Gujarat and Tamil Nadu was sent in July 2022.		
The Indian National Centre for Ocean Information Services (INCOIS)	Request to obtain historical data on Potential Fishing Zones (PFZ's) in Tamil Nadu send in October 2021, and a gentle reminder sent in December 2021. A further request to obtain fishing and aquaculture data in Gujarat and Tamil Nadu was sent in July 2022.	No response received so far – either on the initial request, the gentle reminder or the latest request from July 2022.	Follow-up with INCOIS based on the maritime spatial planning report and the specific data and details focusing on fisheries.
The Archaeological Survey of India	Request to confirm the restriction zones around two (2) ASI protected sites in Tamil Nadu send in October 2021. and a gentle reminder send in December 2021. A further request to confirm the restriction zones around ASI protected sites and information of known underwater archeological sites in Tamil Nadu and Gujarat was send in July 2022.	No response received – either on the initial request, the gentle reminder or the latest request from July 2022.	Follow-up with Archaeological Survey of India based on the maritime spatial planning report and the specific data and details focusing on the aspects of cultural heritage including protected sites and potential submerged archaeological sites such as sunken villages.

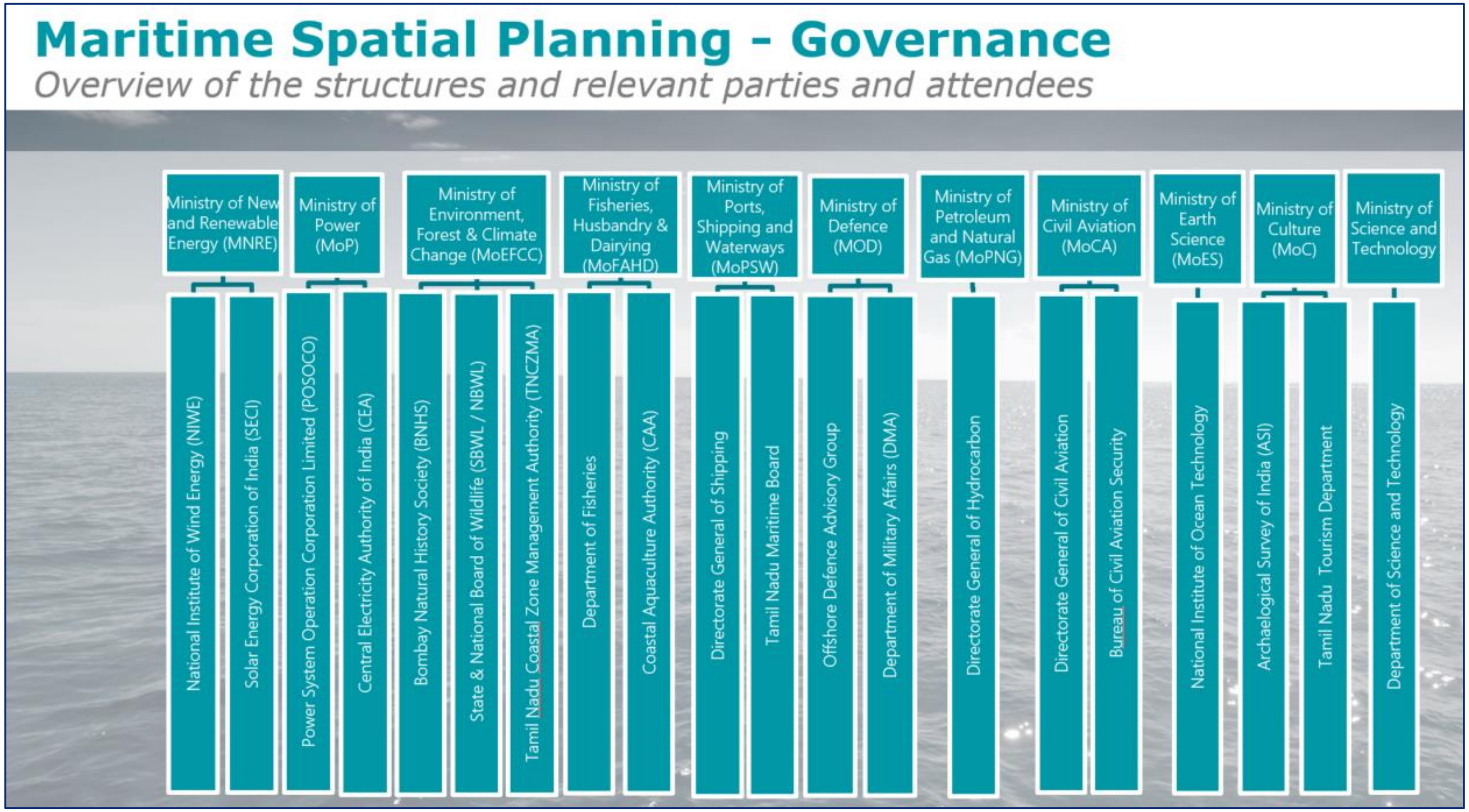
The Ministry of Defence (MoD)	Request to obtain information on presence of static IAF Radar's in Tamil Nadu send in October 2021. A further request to confirm in-principle clearance and obtain information on presence of static IAF Radar's in Tamil Nadu and Gujarat was send in July 2022.	No response received.	Follow-up with MoD based on the maritime spatial planning report to obtain information on presence of static IAF Radar's and confirm in-principle clearance.
The Ministry of Petroleum and Natural Gas (MoPNG)	Request to obtain information on offshore oil and gas installations in Tamil Nadu. A further request to obtain information on offshore oil and gas installations in Tamil Nadu and Gujarat was send in July 2022. This request also included the initial findings with regards to existing oil and gas fields, platforms, pipelines and activities.	No response received.	Follow-up with MoPNG based on the maritime spatial planning report to obtain information and relevant input regarding existing and future oil and gas activities with the purpose of assessing the opportunities for deployment of offshore wind and the co-existence between the two industies.
Geological Survey of India (GSI)	Access to geoscientific data and reports offshore southern Tamil Nadu region send in December 2021.	GSI has provided the readily available and unrestricted data on sediment distribution.	Arrange a follow-up meeting with GSI to understand what information would be available and could be used for the future maritime spatial planning purposes and general de-risking of the future offshore wind development.

		Further they have informed that, various data sets on bathymetry, sediment distribution- surface and subsurface sampling, geo-chemical studies, micropaleontological studies, heavy mineral studies etc. in the specified eight zones have been generated by GSI and certain reports are also available for these areas. However, sharing of these data would require some time as most of them are not available in the public domain and the data needs to be processed as per extant policy	
Central Electricity Authority (CEA) and Central Transmission	Sharing of experience and insights to ensure grid planning for offshore wind	Workshops held with good attendance 21st December 2021 and 7th March 2022. The level of engagement at	Sharing of Electrical note and list of questions to further progress the engagement and planning of the grid for offshore wind.

Utility (CTU) / PowerGrid (PGCIL)		the workshops has clearly shown high interest with a lot of good discussions.	Based on the various questions a series of workshops or regular expert-to-expert technical meetings will be arranged.
Directorate General of Hydrocarbons (DGH)	Request to have a meeting with DGH to obtain feedback and consultation on coexistence of oil & gas and offshore wind in the OWF zones of Tamil Nadu and Gujarat	A meeting is held on 10-11-2022 in the premises of DGH and a discussion on coexistence was held resulting in a conclusion that coexistence is possible as long as close collaboration and communication is held between MNRE and DGH.	It will be beneficial to maintain constant communication, which is already in motion between DGH and MNRE.

1.3 Proposed future engagement with Indian authorities

Besides the continued engagement with the above Indian stakeholders it would also make sense to initiate engagement with some of the below specified authorities in relation to the development of offshore wind and maritime spatial planning project.


Maritime Spatial Planning - Governance
Overview of the structures and relevant parties and attendees
Ministry of New and Renewable Energy (MNRE)
National Institute of Wind Energy (NIWE)
Solar Energy Corporation of India (SECI)
Ministry of Power (MoP)
Power System Operation Corporation Limited (POSOCO)
Central Electricity Authority of India (CEA)
Ministry of Environment, Forest & Climate Change (MoEFCC)
Bombay Natural History Society (BNHS)
State & National Board of Wildlife (SBWL / NBWL)
Tamil Nadu Coastal Zone Management Authority (TNCZMA)
Ministry of Fisheries, Husbandry & Dairying (MoFAHD)
Department of Fisheries
Coastal Aquaculture Authority (CAA)
Ministry of Ports, Shipping and Waterways (MoPSW)
Directorate General of Shipping
Tamil Nadu Maritime Board
Ministry of Defence (MOD)
Offshore Defence Advisory Group
Department of Military Affairs (DMA)
Ministry of Petroleum and Natural Gas (MoPNG)
Directorate General of Hydrocarbon
Ministry of Civil Aviation (MoCA)
Directorate General of Civil Aviation
Bureau of Civil Aviation Security
Ministry of Earth Science (MoES)
National Institute of Ocean Technology
Ministry of Culture (MoC)
Archaeological Survey of India (ASI)
Tamil Nadu Tourism Department
Ministry of Science and Technology
Department of Science and Technology

Stakeholder	Way forward
Ministry of Environment, Forest & Climate Change and relevant agencies	It would be relevant to share the maritime spatial planning report and the background reports from The Biodiversity Consultancy to engage with the relevant parties at either the Ministry and/or relevant agencies.
Ministry of Fisheries, Husbandry and Dairying and relevant agencies	As we have not received any feedback from our request to CMFRI or INCOIS, it might make sense to reach out to relevant parties at either the Ministry and/or the relevant agencies. As part of the engagement, it would be relevant to share the maritime spatial planning report.