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PROGRAMME 2021 – 2027

BEYOND - Blue Economy sYnergies fOr sustainable Development

D.1.3.2 Pilot regions physical natural conditions analysis of deliverable

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Standard Call for Proposals

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Content

1. Introduction

Offshore wind farms (OWFs) are becoming increasingly popular as a renewable energy source, experiencing significant growth worldwide. Currently, there are no OWFs in the Adriatic Sea, making this project among the first to explore their potential installation in the region. This represents a crucial step for the Adriatic, aligning with European Union goals regarding renewable energy targets. As part of this Interreg project, focused on collaboration between Italy and Croatia, the feasibility of constructing OWFs in the Adriatic Sea will be analyzed. The construction of OWFs is a complex process that requires detailed analysis. This process involves evaluating numerous factors that can influence both the operation and installation of OWFs. Many of these factors are related to physical and natural conditions, which can also act as constraints for OWF development. Among these, two key factors for OWF construction are wind speed at the planned OWF location and water depth.

Wind speed plays a crucial role, as OWFs can only operate within specific wind speed ranges. Outside these ranges, installation is not cost-effective. For example, very low wind speeds reduce OWF efficiency, making installation unsuitable. On the other hand, very high wind speeds can damage turbine blades so turbines need to shut down. The second natural critical factor for OWF construction is water depth, which greatly influences the choice of wind turbine foundation type and can also limit installation possibilities. Floating structures are typically used in deeper waters, while fixed-bottom foundations are used in shallower waters. Furthermore, just like with wind speeds, there are specific depth ranges where installing wind turbines becomes unfeasible, particularly in very deep waters.

Besides water depth and wind speed, there are several other natural factors that influence the technical feasibility of OWFs, such as sea currents, hazard zones, seabed substrate type, wave conditions, salinity, sea and air temperature, and others. The major factors and those with the highest influence depend on the specific location. For example, some regions may have very strong waves, which can be a big problem for OWF construction. This means that each location's specifics determine which additional natural factors need to be analyzed.

Thus, this report within the Interreg project, alongside the two main factors, water depth and wind speed, will analyze additional factors such as seabed substrate, hazard zones, air and sea surface temperature, sea salinity, sea currents, and wave conditions. The influence of these natural factors on offshore wind turbines will be described, along with the used dataset and results for each pilot location. At the end, a conclusion will be drawn based on the examined results, with recommendations and a summary for each location.

2. Test locations

Four potential locations have been selected: two within the Italian border and two within the Croatian border (*Figure 2.1*). Two of these locations are situated in the northern, shallower part of the Adriatic, while the other two are located in the southern, deeper part of the sea.

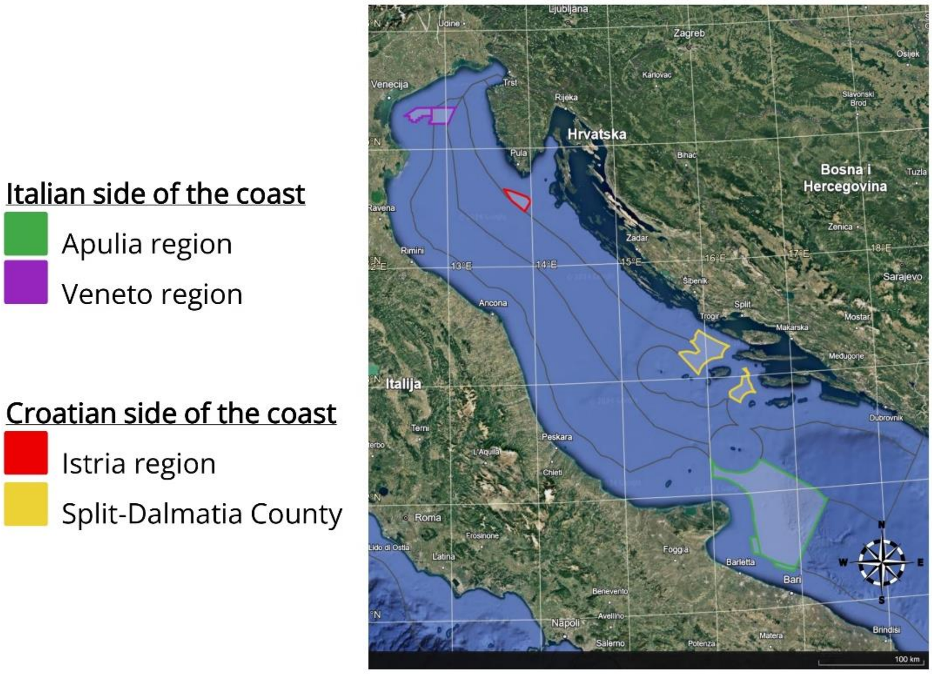


Figure 2.1. *Locations of test regions [1]*

The Veneto pilot region is the northernmost region among all four regions. This region consists of two mutually connected polygons, which together cover just below 490 km² (*Figure 2.2*). Of that, the larger and eastern polygon covers approximately 290 km², while the smaller and western polygon covers around 195 km². The western polygon is located completely within the territorial sea of the Republic of Italy, while the eastern territory is located partly within the territorial sea of the Republic of Italy, and partly within the exclusive economic zone of the Republic of Italy. There are no islands near these regions. The nearest shore is the Italian mainland, located to the west of the Veneto region. Each part of the polygon is situated around 20 km from the mainland. A large number of settlements are located along the Italian mainland shore, within a 30 km radius of the Veneto regions. The largest of these settlements is Venice, where the electricity transformer station is also located. The city of Venice itself has over 250,000 inhabitants, while the wider metropolitan area has around 2.6 million inhabitants. Moreover, along the western Istrian coast, there is also a sequence of settlements from north to south. However, these settlements, compared to those in Italy, are slightly farther away from the Veneto polygons, within a distance of about 45 km.

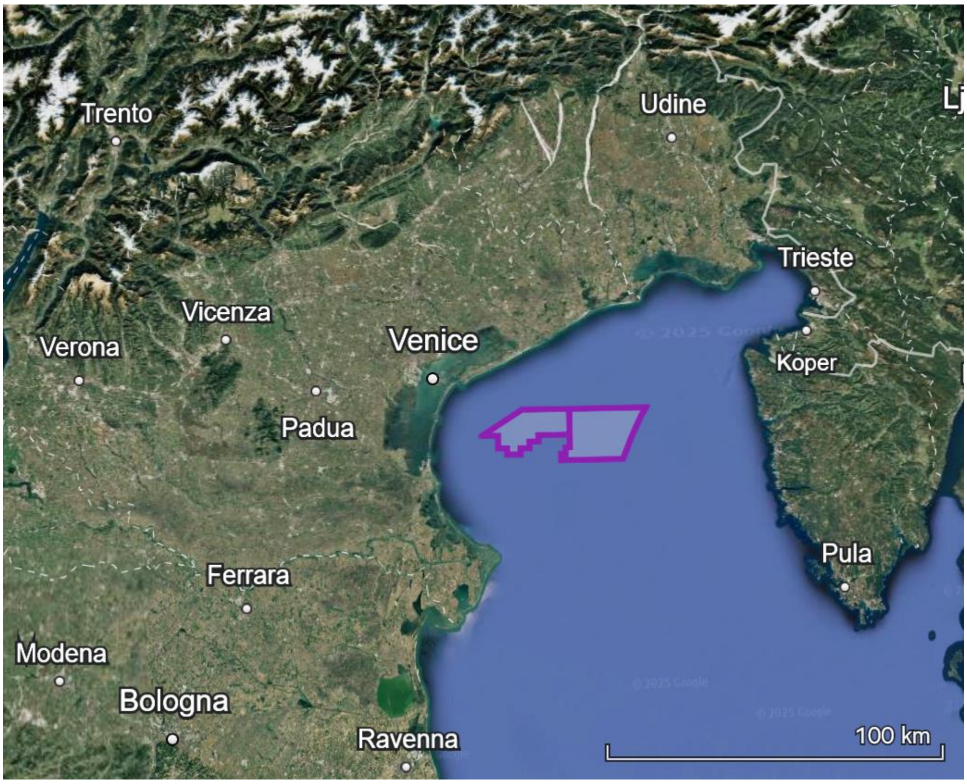


Figure 2.2. *Veneto pilot Region [1]*

The Istrian pilot region is located approximately 20 km south of the Istrian peninsula (*Figure 2.3*). The polygon is triangular in shape, oriented northwest-southeast, and covers an area of approximately 220 km². The entire polygon is located within the territorial sea of the Republic of Croatia. The nearest populated area to this region is the town of Premantura, less than 25 km away. The largest city in the vicinity of this region is the city of Pula, but the planned closure of the Plomin Thermal Power Plant will result in a shortage of electricity for the entire Istrian peninsula, which has a population of approximately 200,000 and a large number of tourists. The nearest large electricity transformer station to this pilot region is located near the Plomin Thermal Power Plant, approximately 65 km northeast.

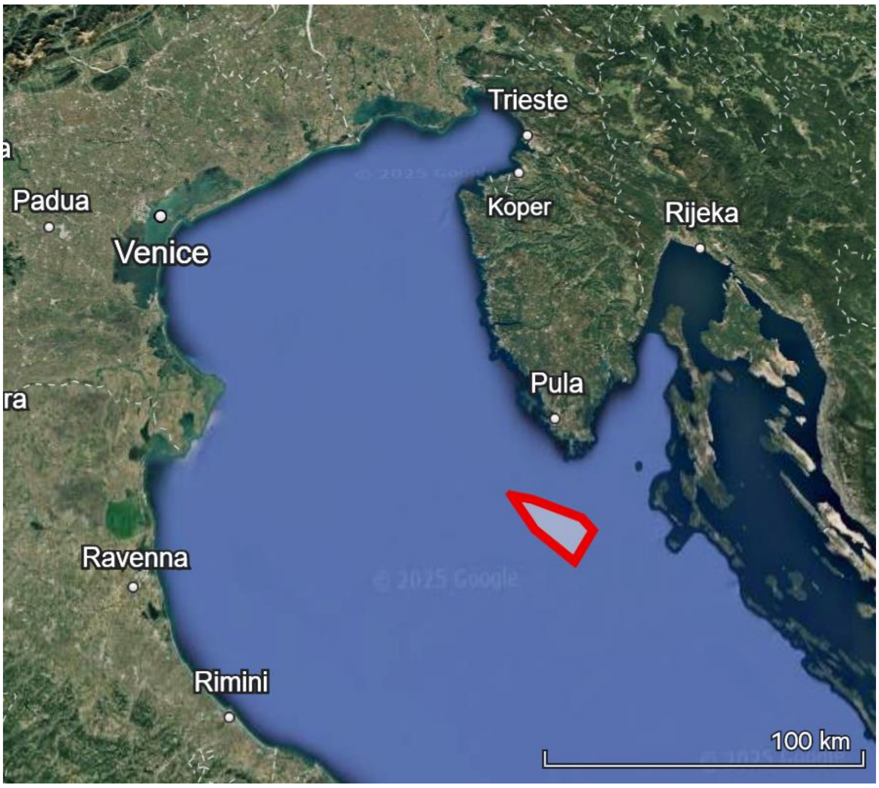


Figure 2.3. *Istrian pilot Region [1]*

The Split-Dalmatia pilot region consists of two separate polygons. The northwestern polygon is closer to the mainland, while the southeastern polygon is surrounded by islands (*Figure 2.4*). The Split-Dalmatia pilot region covers a total area of about 1,069 km². Of this, the northwestern area covers about 800 km², while the southeastern area covers a little over 270 km². The larger islands in the vicinity of the Split-Dalmatia pilot regions are Hvar, Korčula, Brač, etc. Furthermore, in addition to these nearby islands, there are a number of settlements located along the Croatian coast within a radius of 30 km, including the cities of Trogir and Split and many other settlements. The city of Split is the largest consumer of electricity in the vicinity of the pilot regions, with a population of 160,000, while the entire Split-Dalmatia County has a population of almost 500,000. Each part of the Split-Dalmatia pilot region is more than 10 km from the islands and the mainland coast. In addition, the nearest major electricity transformer station is located in the city of Split.

Figure 2.4. *Split-Dalmatia pilot Region [1]*

The Apulia pilot region is the largest of the three regions mentioned above. This region consists of three interconnected areas (*Figure 2.5*). In total, these three areas cover more than 5630 km² of sea. Of this, the largest and central polygon occupies more than 95% of the total area, or approximately 5400 km², while the other two together cover less than 5% of the total area, each with an area slightly less than 100 km². Two smaller polygons are located within the territorial sea of the Republic of Italy, while the largest polygon is located within the exclusive economic zone of the Republic of Italy. There are no large islands around these polygons. Furthermore, there are a number of settlements located along the coast of the Italian mainland within a radius of 30 km, from north to south. The largest city in the vicinity is Bari with 315,000 inhabitants in the urban area and 750,000 in the wider urban area. The city is located about 20 km southwest of the test regions, where the nearest major electricity transformer station is located.

Figure 2.5. *Apuglia pilot Region [1]*

3. Physical conditions

Many factors impact the OWF, and these factors serve as constraints when planning its construction. One of these factors is physical conditions, which cannot be changed. The two most important physical conditions that must be examined when planning an OWF are water depth and wind speed. Additionally, there is a sequence of other physical conditions that could influence the construction and operation of the OWF, potentially affecting the efficiency of the wind farm. Some of these additional factors are not always considered or examined. Which factors will be analyzed depends on the specifics of the location. For the four test regions in the Adriatic Sea, the additional physical factors to be analyzed include seabed substrate type, seismic hazard zones, air and sea temperature, salinity, sea currents, sea surface height and wave conditions. Other physical factors, such as precipitation and sea ice occurrence, will not be examined since the impact of these factors in the Adriatic Sea is negligible.

Table 3.1. *Considered physical natural conditions*

Main factors	Additional factors
▪ wind speed ▪ sea depth	▪ seabed substrate type ▪ seismic hazard zones ▪ air temperature ▪ sea temperature ▪ salinity ▪ sea currents ▪ sea surface height ▪ wave conditions

3.1. Data sources

To analyze the relevant physical natural conditions for the planned pilot regions in the Adriatic Sea, it is essential to use online databases to gather the necessary data. For wind data at specific locations, free sources like the Global Wind Atlas (GWA) [2], based on ERA5 reanalysis data, or the New European Wind Atlas (NEWA) [3] can be utilized, depending on the location of the offshore wind farm (OWF) and the required resolution of the data. Additionally, to examine the bathymetry of the pilot regions, open-source databases such as the European Marine Observation and Data Network (EMODnet) or the General Bathymetric Chart of the Oceans (GEBCO) can be used. European online datasets are frequently updated, and these platforms are continuously improving to provide more accurate data for the areas they cover, therefore, these datasets will be used for further analysis.

3.1.1. New European Wind Atlas (NEWA)

NEWA is a wind atlas website which provides high-resolution mesoscale and microscale data that was modelled to cover the European Union and Turkey, extending at least 100 km from the coastline. The mesoscale modelling covers data from 1989 to 2018, which is a total of 30 years, but mesoscale data is available only from 2008 to 2018 with a temporal resolution of 30 min timestep. Mesoscale data can be obtained at a spatial resolution of 3 km grid spacing, while microscale data can be obtained at a spatial resolution of 50 m grid spacing. Besides wind speed, other variables such as air temperature, air density, etc. can also be obtained. NEWA can be helpful to many different types of users such as researchers, wind farm developers and policy makers considering its high quality and vast available data, which justifies its use in industry. NEWA web Services are presented in Figure 3.1.

Data for the desired variable are downloaded using the NEWA Mesoscale Time-series API. To make a request to the API service, latitude and longitude values for a specific geographical point or a rectangular area (bounding box) must be provided, along with height and time range. Temporal data can only be acquired for the mesoscale spatial resolution.

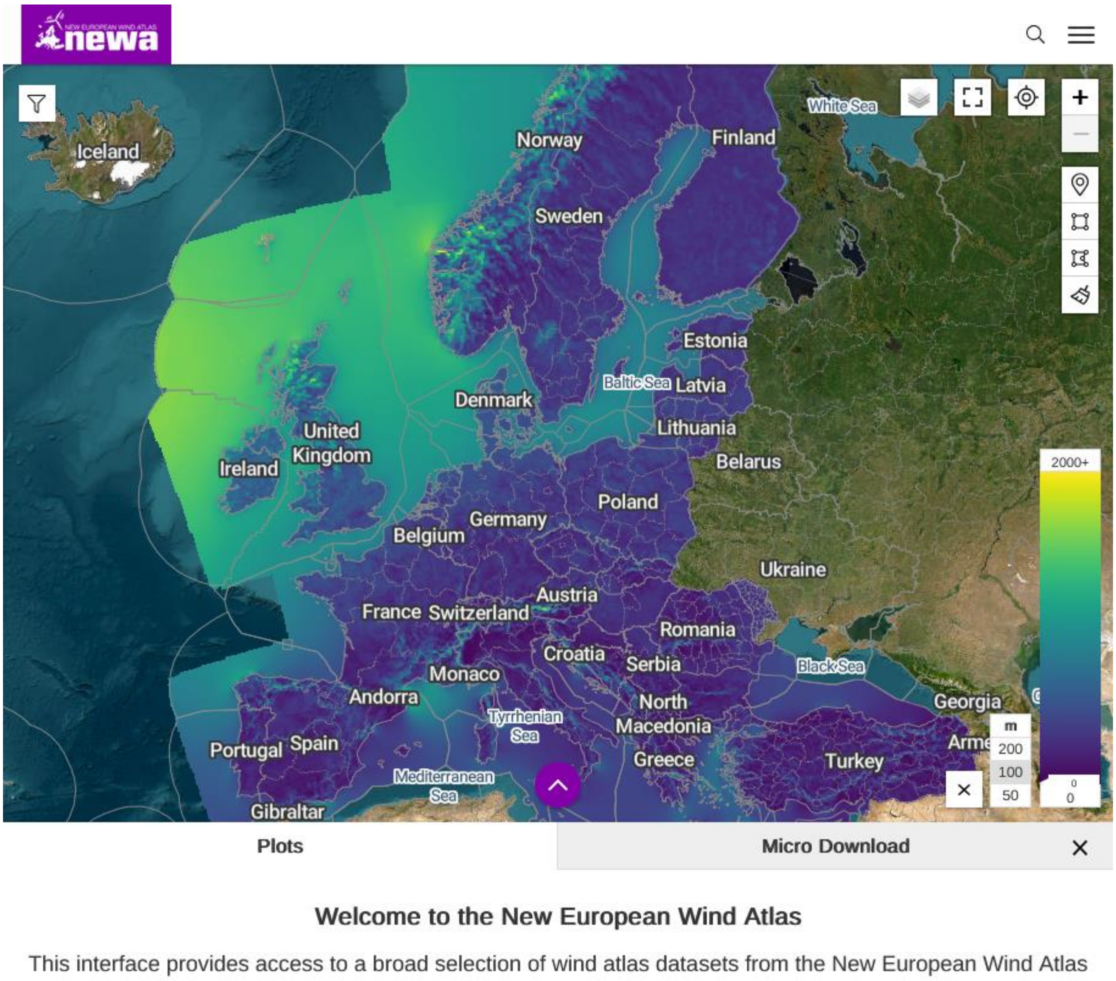


Figure 3.1 *NEWA Web Services [3]*

3.1.2. EMODnet

The European Marine Observation and Data Network (EMODnet) is the marine data service of the European Commission's (EC) Directorate-General for Maritime Affairs and Fisheries (EC DG MARE). Established in 2009 with funding from EC DG MARE and the Aquaculture Fund, EMODnet plays a central role in providing access to data on marine environments and human activities, forming a foundation for various sectors. The EMODnet Portal [1] serves as a single access point for all EMODnet services, offering easy and free access to a wealth of marine data, metadata, and data products. The portal covers various thematic areas, including bathymetry, geology, and many others. EMODnet Map Viewer is presented in Figure 3.2.

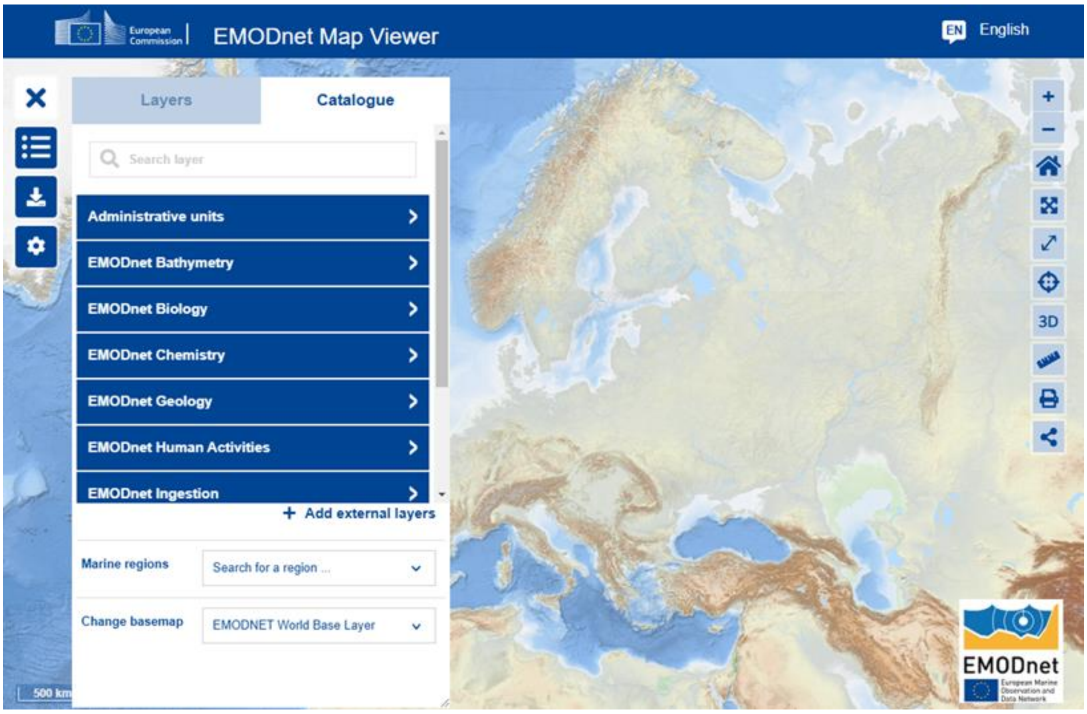


Figure 3.2. *Options and possibilities in EMODnet Map Viewer [4]*

EMODnet covers the entire marine environment, from the coast to the open ocean, enabling research on both surface waters and the deep seafloor. EMODnet experts have developed unique data products, including EUSeaMap, a broad-scale seabed habitat map, the EU Digital Terrain Model for harmonized bathymetry, and others. This dynamic network of experts continues to enhance EMODnet, shaping it into the operational EU marine data service it is today. In addition, EMODnet offers a public Data Ingestion service to expand and diversify its data offerings.

[1] https://emodnet.ec.europa.eu/geoviewer/

Currently, EMODnet collaborates with the General Bathymetric Chart of the Oceans (GEBCO), exchanging data and complementing each other's resources. Through EMODnet, a wide range of data can be downloaded, including a bathymetry chart with a resolution of 115 m across Europe and a bathymetry chart with a resolution of 500 m globally. This is highly useful, as bathymetry data, together with wind data, are the most important factors that must be analyzed before constructing an OWF.

3.1.3. Copernicus Marine Service

Copernicus is a component of the European Union's space programme for Earth observation which provides many services based on data from satellites, and ground-based, seaborne and airborne measurement systems along with numerical models. The European Commission manages the Copernicus program in partnership with the Member States, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) the European Space Agency (ESA) and other organizations. The goal of the program is to provide full, free and open data in support of tackling global challenges and help to understand the planet better and sustainably manage the environment. The Copernicus services consist of six thematic areas: Atmosphere Monitoring Service, Marine Service, Land Monitoring Service, Climate Change Service, Emergency Management Service and Security Service.

Copernicus Marine Service or Copernicus Marine Environment Monitoring Service (CMEMS) provides systematic and regular information on the state of the ocean's physical state, dynamics and marine ecosystems on a global scale and for European regional seas. Operated by Mercator Ocean International, CMEMS offers products such as reanalysis, near real-time data and forecasts data for various applications including environmental monitoring, climate science, resource management and maritime safety. Available variables included different oceanographic parameters, such as sea surface temperature, salinity, sea currents, sea surface height and wave conditions, which can be useful for determining physical conditions for planning OWF. Copernicus Marine data can be accessed using several different ways. One of them is using MyOcean Pro Viewer [5] presented in Figure 3.3 which allows the visualisation and downloading of oceanic data.

Figure 3.3. *MyOcean Pro viewer [5]*

3.2. Wind speed

Offshore wind parks or farms (OWF) offer more energy production potential due to generally steadier and stronger winds than inland areas. In the absence of obstacles on the sea, the wind is less turbulent, which, including greater wind speeds at sea, leads to greater energy production and a major reduction in fatigue on the turbine's structural components. OWFs should be installed in areas with high wind speeds, making an accurate and detailed analysis of wind data essential. Wind speed potential can be quantitatively expressed through the mean values at heights of 10, 80, or 120 m above the mean sea level. In addition to the annual average wind speed, effective wind hours are also factors of interest that should be examined. Depending on the available wind speed data for a specific location, the most suitable type of wind turbine will be selected. Figure 3.4 shows the mean long-term modelled wind speed over the Adriatic Sea from New European Wind Atlas, with 4 BEYOND Pilot Regions indicated by black polygons.

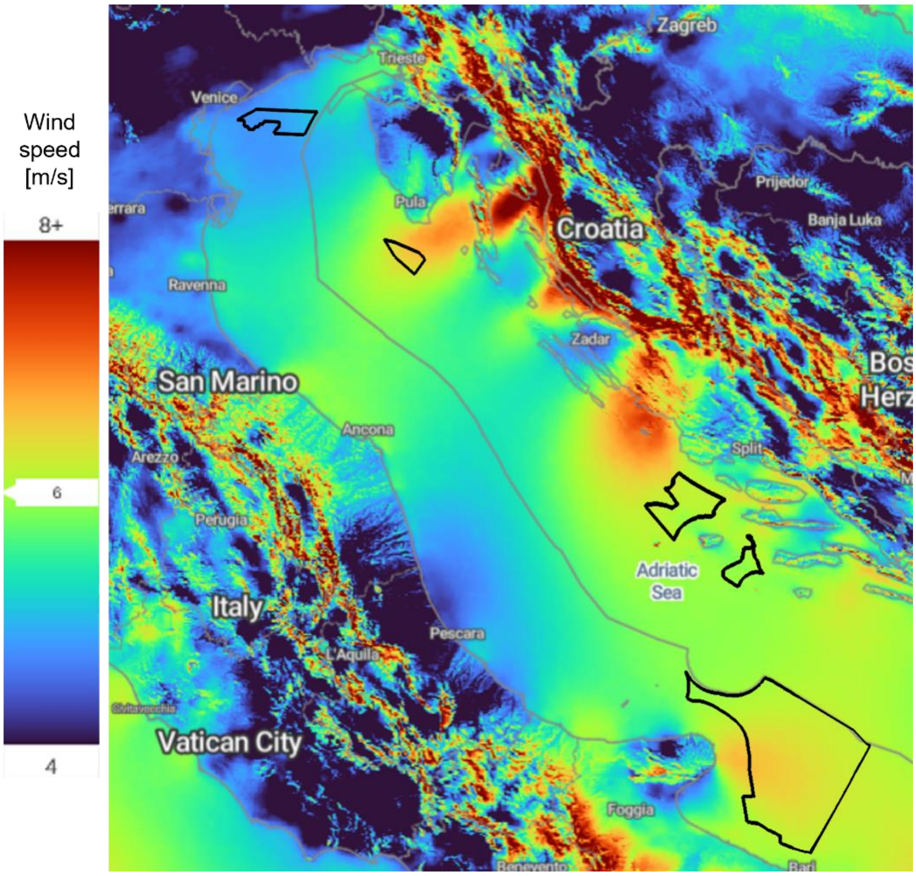


Figure 3.4. *Mean long-term modelled wind speed with marked 4 Pilot Regions [3]*

3.3. Water depth

Water depth is the crucial factor for planning investment and choosing adequate foundation types of offshore wind farms. Water depth has a significant impact on the cost of installation, as costs increases considerably with deeper waters. The depth of the water determines the type of wind turbine support structure and its foundation. In shallower waters, turbine foundations are mounted directly on the seafloor, whereas in deeper waters, floating wind turbines are selected. The depth limit for choosing between floating and fixed turbines are limited in water depth up to 50 m [6], based on the economic viability of OWFs and market maturity. While floating wind turbines can be used in much deeper waters, there are still specific design and cost challenges. Figure 3.5 represents water depth data obtained from the previously mentioned database EMODnet Map Viewer [4] for the Adriatic Sea, where black polygons represented regions of interest.

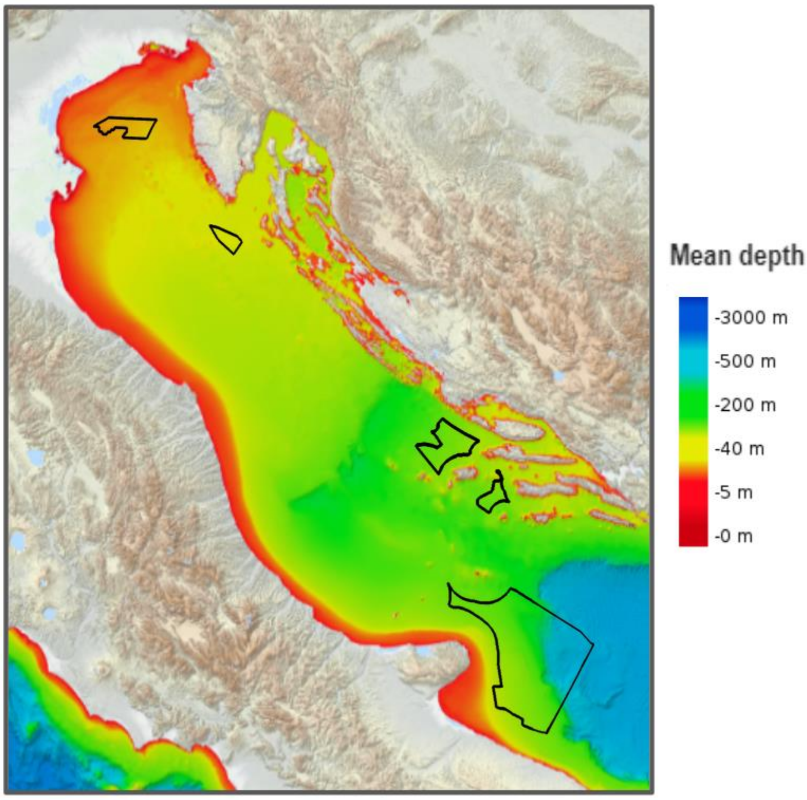


Figure 3.5. *The mean depth of the Adriatic Sea with highlighted four regions of interest [4]*

3.4. Additional factors

Chapter 3.4 analyzes additional factors that, although not as crucial as sea depth and wind speed, can significantly impact the installation and long-term efficiency of offshore wind farms. These factors include seabed substrate type, seismic activity, air and sea temperature, salinity, sea currents, sea surface height, and wave conditions. While they do not directly affect energy production, they play a key role in foundation selection, structural stability, maintenance, and material corrosion protection, making them essential for later stages of planning and operational efficiency.

3.4.1. Seabed substrate type

Knowing the seabed type at the planned offshore installation location is important. It influences the decision on how the wind turbine pylons will be fixed and mounted. There are many classifications that define seabed types. One of them is the Folk classification, which is available for the Adriatic Sea. The Folk classification defines seabed substrates based on grain size [7]. There are several versions of the Folk classification, depending on how precisely the seabed type needs to be described and how accurate the seabed data is. The most precise, Folk 16, describes 16 different types of seabed substrate. Next is Folk 7, which defines 7 different types of seabed substrate. The least detailed, Folk 5, defines only 5 different types of seabed substrate. In the characterisation of the seabed type for pilot locations in Adriatic Sea, the Folk 7 classification was used. This classification uses a ternary diagram in which each of the three peaks represents one of the three basic grain types: gravel (grain size between 2–64 mm), sand (grain size between 6.25 µm and 2 mm), and mud (grain size less than 6.25 µm) (*Figure 3.6*). The remaining substrates are defined as the proportion of each basic grain type. In Figure 3.7 seabed types for each pilot location are presented.

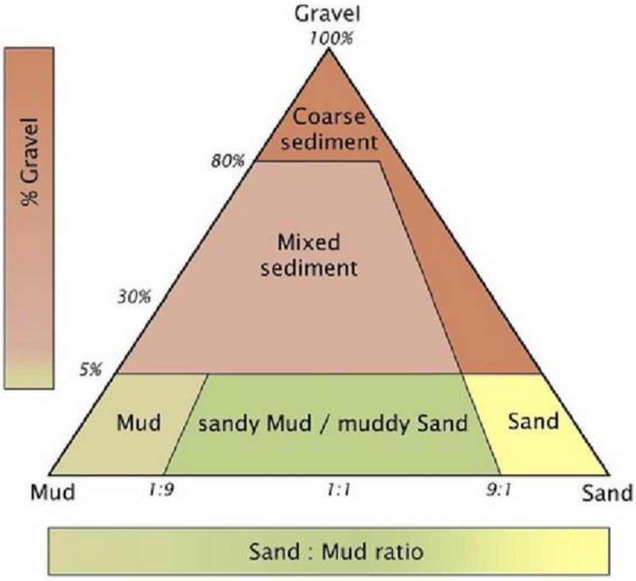


Figure 3.6. *Folk 7 classification [7]*

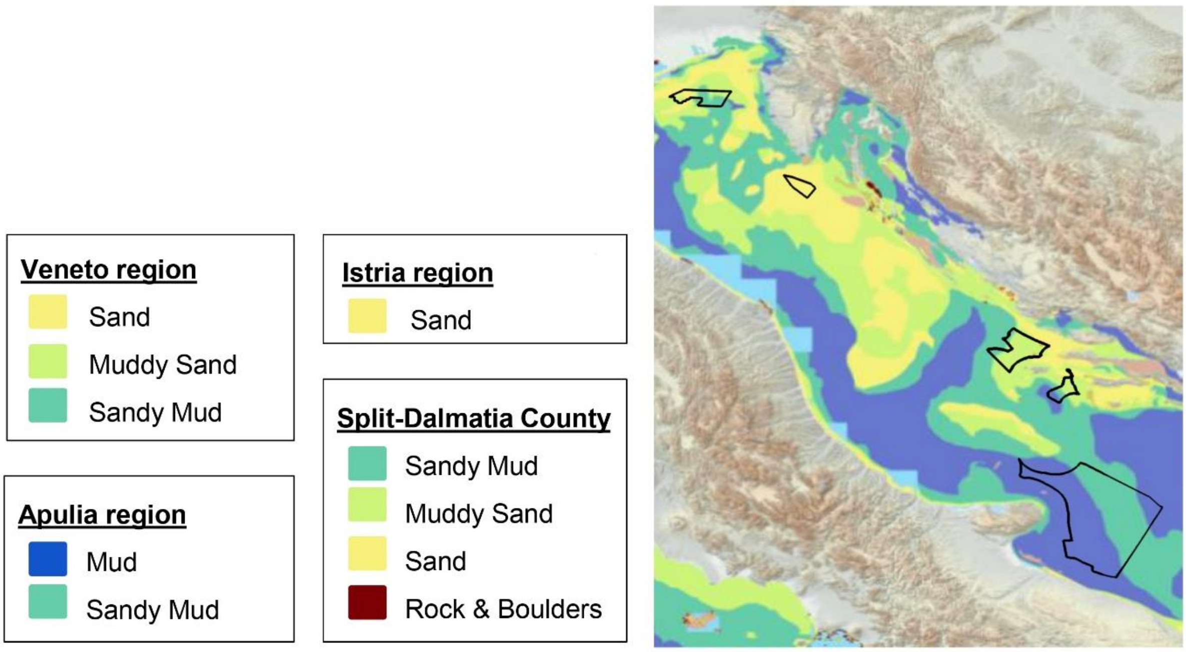


Figure 3.7. *Folk 7 classification for the Adriatic Sea with highlighted four regions of interest [4]*

According to the data provided by the Croatian Hydrocarbon Agency, the seafloor of the Adriatic Sea is composed of Pleistocene sediments, primarily medium-grained sand and fine-grained silt, which are poorly consolidated. These sediments are distributed in such a way that their thickness decreases as you move toward the Croatian coastline. Moreover, these Pleistocene sediments completely disappear after crossing the boundary that roughly marks the Croatian border of internal waters. Over these sediments, Holocene deposits have accumulated, forming the substrate of the present-day Adriatic seabed. The thickness of the Holocene deposits decreases toward the east. However, unlike the Pleistocene sediments, Holocene deposits extend further along the Croatian coastline. Between the line marking Croatian internal waters and the Croatian coastline, the thickness of the Holocene quaternary sand and silt reaches approximately 70 meters. In contrast, the thickness of the Holocene quaternary sand and silt increases as you move toward the Italian coastline.

3.4.2. Hazard zones

The hazard zone analysis can also be considered an additional physical factor that may influence the construction of OWFs. To achieve this, a seismic hazard map of the Adriatic Sea was used (*Figure 3.8*). This map shows the expected ground motion caused by earthquakes over a specific period at a particular location [8]. Additionally, ground motion is measured and compared to Earth's gravitational acceleration (g). Based on the ESHM20 catalogue, the intensity of these movements categorizes the ground motion into 9 categories. Furthermore, this seismic hazard map shows the expected horizontal acceleration at 5 Hz. However, to assess the local hazard, it is necessary to examine the subsoil conditions at that specific location.

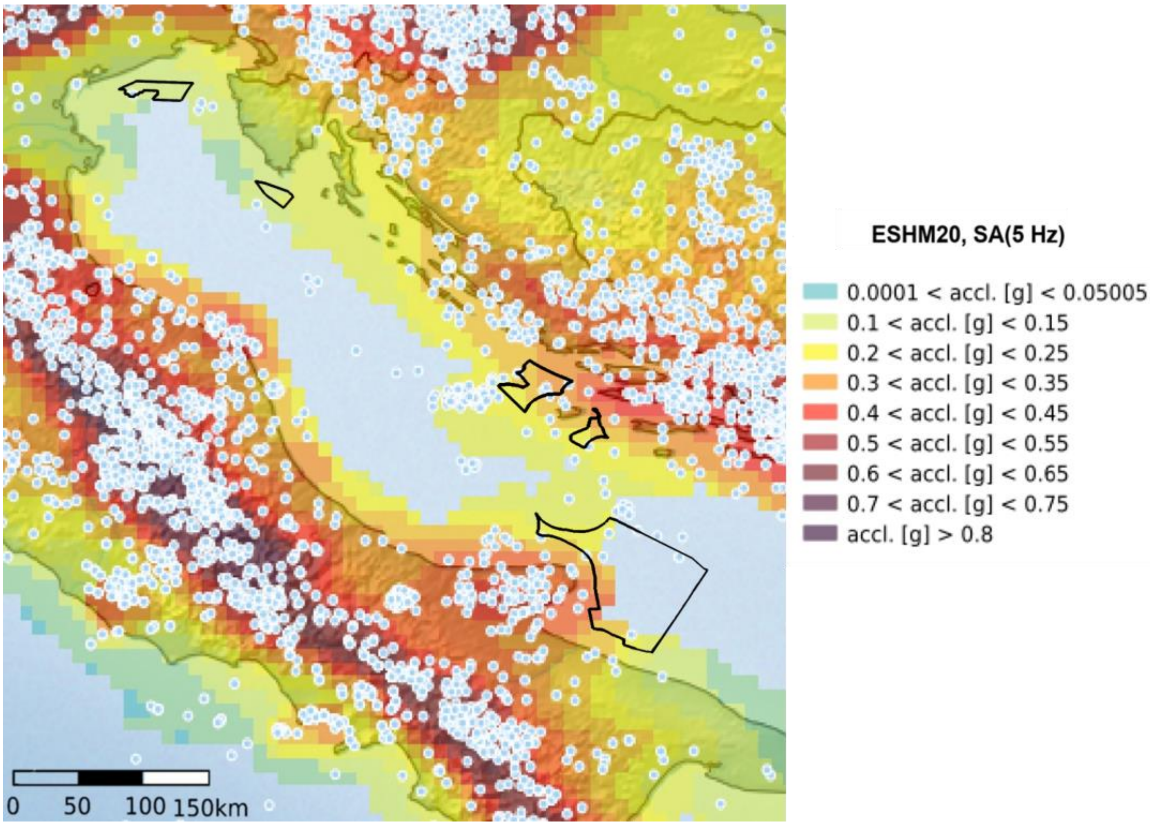


Figure 3.8. *Seismic hazard map [8]*

From Figure 3.8, it is evident that the Adriatic Sea does not generally experience significant ground motion caused by earthquakes. Almost the entire central Adriatic does not belong to any of the intensity groups of ground movements caused by earthquakes. Therefore, it will not be analyzed for pilot regions in more detail. In the northern and northeastern Adriatic, there is a belt parallel to the shore, which belongs to the second intensity group of ground movement, although these movements are still very minimal. Furthermore, there are some areas in this part of the Adriatic that fall into a lower intensity group for ground movements caused by earthquakes. Nearly the entire narrow strip along the Italian border belongs to the mid-range intensity group of ground movements caused by earthquakes, as well as areas along the Croatian central and southern mainland borders, where the intensity group is even stronger. In this region, near the shores of Italy and Croatia, the intensity of ground movements gradually increases from the very low intensity group in the north to the mid-range intensity group in the south. Additionally, Figure 3.8 shows the points representing locations where earthquakes have been recorded so far. It is noticeable that in the northern and central Adriatic, only a few recorded earthquakes are present, while near the Italian shore and along the Croatian central and southern coast, there are numerous recorded earthquake points. This suggests that the locations where earthquakes have been recorded align with areas of higher ground movement intensity, indicating a greater chance of earthquakes occurring in regions with stronger ground motion.

3.4.3. Air temperature

Air temperature is an important factor that directly impacts wind turbine performance. Lower temperatures have a positive effect on both the lifespan of the turbine and the amount of power generated, as both increases in colder conditions. The information on air temperature can also be used to calculate air density at higher altitudes using the logarithmic law, in order to determine the correct power output of wind turbines, taking into account the hub height and blade length. Temperature data for each pilot area can be found on wind atlas websites such as Global Wind Atlas and NEWA.

In this report, air temperature values are obtained from the NEWA website [3] at a mesoscale spatial resolution of 3 x 3 km and a time step of 1 hour, with a time range from January 1, 2009, to December 31, 2018, which represents a ten-year period, at the height of 2 m above the sea level. The air temperature dataset matches the wind speed dataset in terms of time range, temporal and spatial resolution.

3.4.4. Sea temperature

Seawater temperature can influence the operational efficiency of turbines, maintenance, and the marine ecosystem. It can influence air density and potentially reduce wind energy production. Seawater temperature can also affect corrosion and material degradation, along with thermal expansion and contraction of materials. Therefore, it is important to know the expected values of seawater temperature at the tested locations.

For analysis of sea water temperature, Mediterranean Sea - High Resolution L4 Sea Surface Temperature Reprocessed [9] from Copernicus Marine Service was used. Sea Surface Temperature (SST) data was obtained using a merged multi-sensor (L3S) and optimally interpolated (L4) satellite-based estimates with 0.05° (around 5 km) spatial resolution over the Mediterranean Sea. Figure 3.9 represents the sea surface temperature for 31.12.2022. obtained from MyOcean Pro viewer [5], which was used for downloading data. For analysis of testing locations, daily values of sea surface temperature were averaged from 1.1.2013. to 31.12.2022.

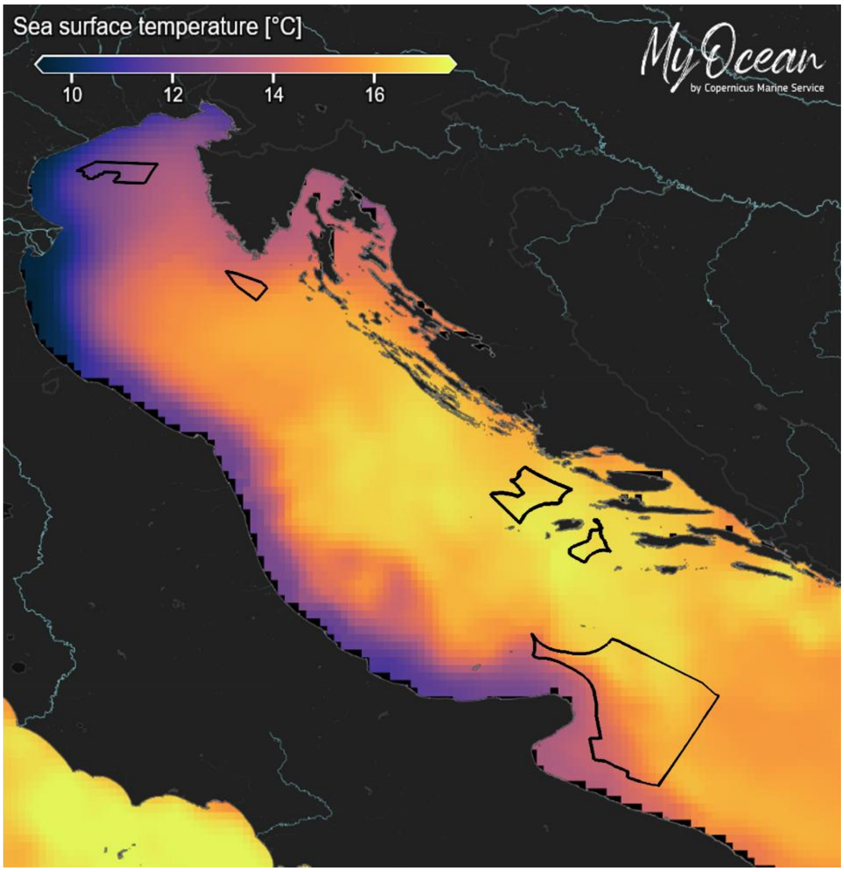


Figure 3.9. *Sea surface temperature for the Adriatic Sea for 31.12.2022. [5]*

3.4.5. Salinity

Salinity influences the planning and maintenance of offshore wind farms and is connected to the marine ecosystem. Higher salinity can accelerate the corrosion of metal components in wind turbines, so proper materials and coatings should be used depending on expected values. Also, higher salinity often requires more frequent inspections and maintenance. Therefore, it is beneficial to know the expected values at tested locations.

Salinity was obtained using the Mediterranean Sea Physics Reanalysis [10] model from Copernicus Marine Service. It uses the NEMO (Nucleus for European Modelling of the Ocean) model for ocean modelling with assimilation of satellite altimetry tracks, in-situ temperature and salinity profiles using the OceanVar 3DVar scheme. The physical reanalysis model for the Mediterranean Sea has 1/24° (4 -5 kilometres) horizontal grid resolution. The temporal coverage depends on the temporal resolution of data, which can be hourly, daily, monthly and yearly. For the physical condition analysis of the pilot location, daily salinity values for the period from 1.1. 2013. until 31.12.2022. were averaged.

3.4.6. Sea currents

Sea currents create loads on wind turbine foundations by exerting hydrodynamic forces but can also influence stability if a higher scour effect occurs, creating erosion around foundations and negatively influencing marine ecosystems. Stronger sea currents can also affect installation by limiting access to turbines and it can increase the risk of damage to subsea power cables. Therefore, knowing current speed can help to properly choose a foundation design, increase structural safety and minimize the cost of maintenance.

To obtain values of current speed, the Mediterranean Sea Physics Reanalysis [10] model from Copernicus Marine Service was used, like for salinity. Results for daily averaged values of current speed near the surface are presented in Figure 3.10 for 31.12.2022. The analysis period of 10 years was the same as for salinity and SST.

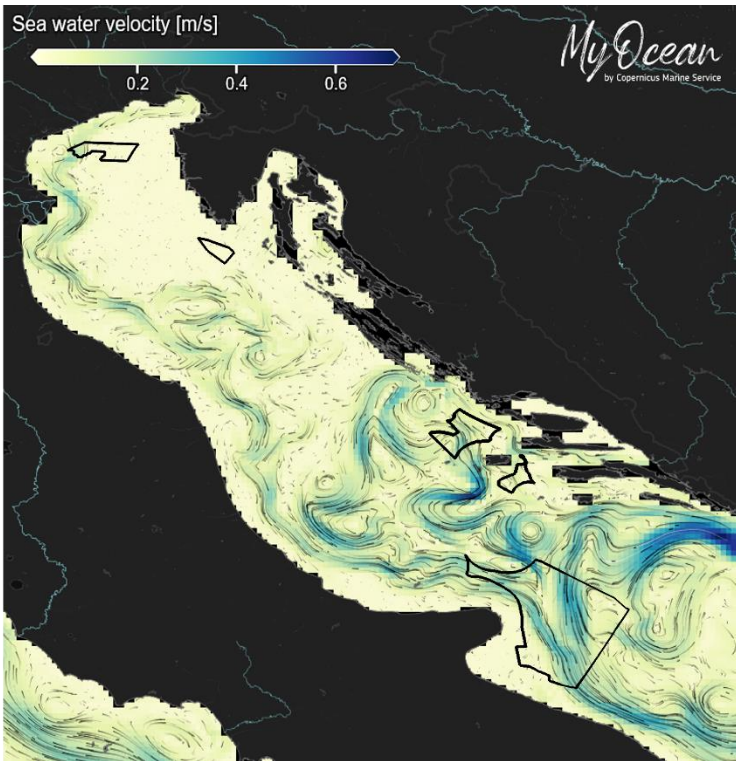


Figure 3.10. *Sea currents near surfaces of the Adriatic Sea for 31.12.2022. [5]*

3.4.7. Sea surface height

To properly design foundations and understand ocean dynamics around wind turbine foundations, it is important to know the expected values of sea surface height. The geoid represents imaginary sea level surfaces with only gravity influences (no tidal and sea currents). Sea surface height above the geoid represents expected changes in water level, therefore it is used to choose an adequate foundation design to ensure stability and withstand hydrodynamic forces. It is also useful for planning maintenance and installation operations.

Values of sea surface height are also obtained from the Mediterranean Sea Physics Reanalysis [10] model provided by the Copernicus Marine Service. Results for daily averaged values of sea surface height are presented in Figure 3.11 for 31.12.2022. A very small change in sea level can be observed in the pilot locations except for the Apuglia region. Pilot location analyses were conducted for the same period as previous sea physical conditions.

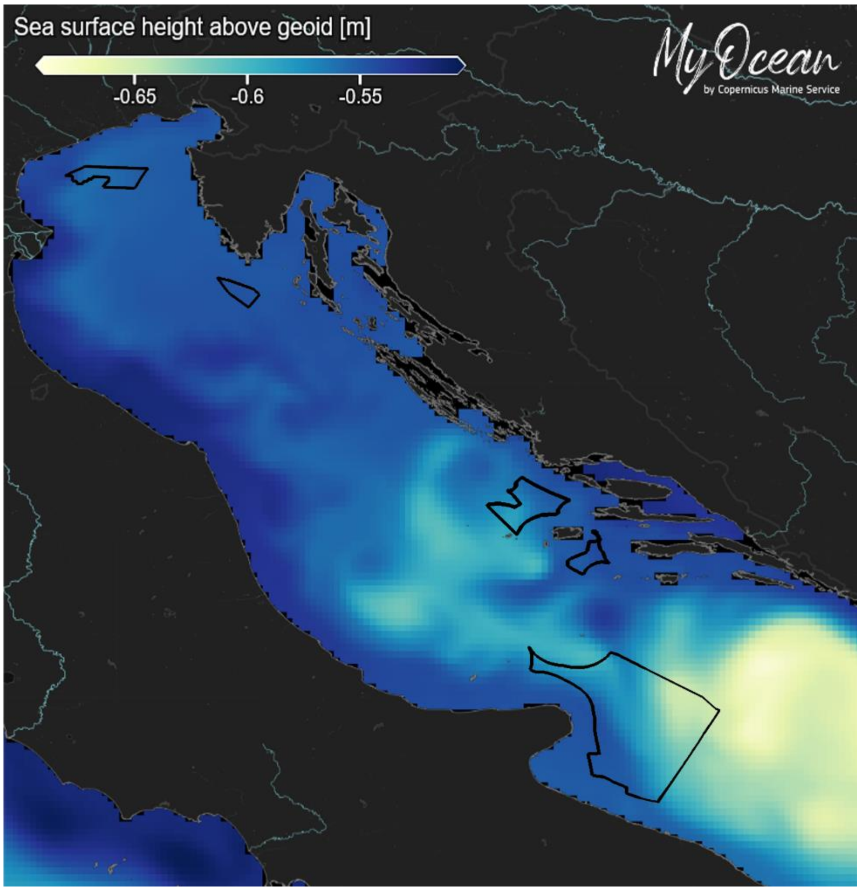


Figure 3.11. *Sea surface height for the Adriatic Sea for 31.12.2022. [5]*

3.4.8. Wave conditions

Waves can significantly influence the stability of offshore wind turbines. Predicting by forces on wind turbine structures exerted by waves, the design of foundations should be adapted to withstand wave impact, cyclic loading, and fatigue stress. High waves or extreme wave events are important for the installation and maintenance of offshore wind farms. Waves also affect power cable stability and marine life. Therefore, analysis of wave conditions is important for adequate offshore turbine foundation selection, along with planning installation and maintenance.

To describe wave conditions variables, including significant wave height, wave mean period and wave direction are obtained from Mediterranean Sea Waves Reanalysis [11]. It uses the WAM wave model and with data assimilation scheme of satellite significant wave height observations. The results of these variables were analysed based on hourly values with 1/24° horizontal grid resolution for the same 10-year period as other ocean physical conditions.

4. Results

This chapter will specifically analyze the physical natural conditions of each of the four OWF installation sites in the Adriatic Sea using the same methodology. A detailed analysis of all these physical factors is essential before constructing the OWF to maximize efficiency and minimize costs.

4.1. Veneto Region

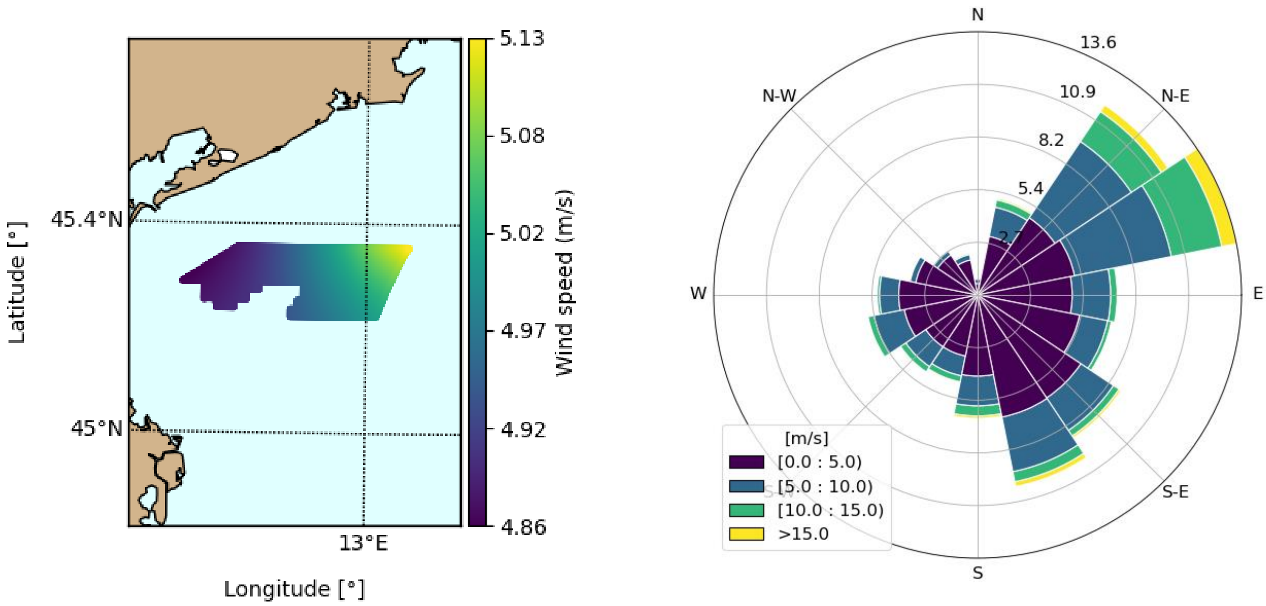
The wind speed and its spatial distribution over the location are analyzed together with the frequency of wind directions. Following the wind analysis, the bathymetry of the location will be examined. Additionally, several physical natural conditions will be analyzed, including seabed substrate, air temperature above the location, sea surface temperature, sea currents, sea salinity, and wave conditions.

4.1.1. Wind speed

The heatmap in Figure 4.1 shows the average monthly wind speed for the Veneto Region over the course of 10 years. Higher values of average wind speed occur mostly during the winter months, namely January, February and March. On the other hand, lower values of wind speed characteristically appear during the summer months, which are June, July, August and September.

Figure 4.1. *Average monthly wind speeds at the Veneto Region for a period of 10 years*

Analysis of wind speed and direction is presented in Figure 4.2 for the Veneto test region obtained by averaging 10 years of hourly data at 100 m above the sea level. Figure 4.2 a) illustrates the spatial distribution of wind speeds at this location. From this distribution, it is clear that the wind speed increases in the northeast direction within the location polygon, where the highest wind speeds are recorded. In contrast, the lowest wind speeds are observed in the southwest of the polygon. Values of average wind speed are constant across the region and range from a minimum of approximately 4.9 m/s to a maximum of around 5.1 m/s, which gives an average value of 5 m/s. By observing wind rose for the Veneto test region, represented in Figure 4.2 b), it can be concluded that the highest wind speeds are recorded from the northeast and east direction, while the opposite, the lowest wind speeds are found in the southwest of the location polygon.



a) b)

Figure 4.2. *a) Averaged wind speed and b) wind rose for the Veneto Region for a period of 10 years*

4.1.2. Water depth

Figure 4.3 shows the bathymetric profile of the Veneto location. Generally, the figure illustrates that this location features a very shallow sea. The sea depths range from a maximum depth of approximately -35.5 m to a minimum depth of -19.5 m. This indicates a difference of just over 10 meters in depth across the entire polygon, which covers an area of approximately 490 km².

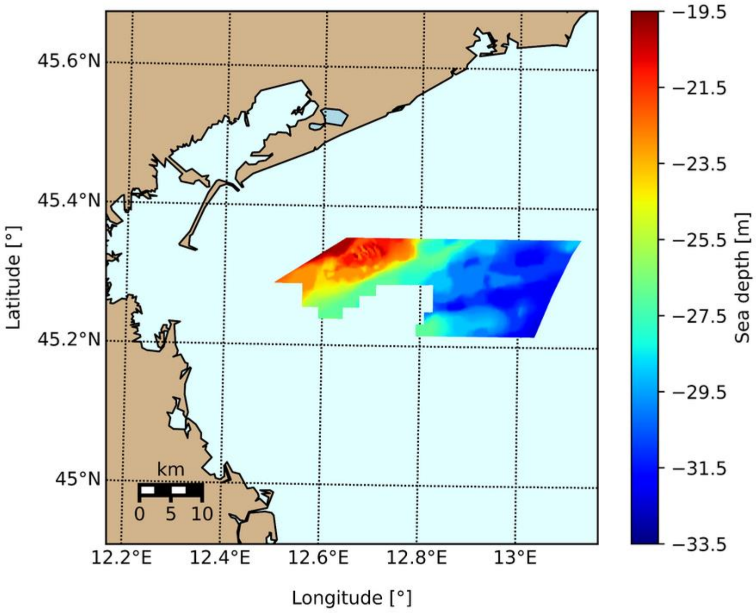


Figure 4.3. *Water depth across the Veneto Region*

4.1.3. Additional factors

In this region, sand, muddy sand, sandy mud, and silt predominantly prevail as the seabed types. This means that driving the foundation into the seafloor will not pose significant challenges. The transition between the mentioned sediment types at this location will not be problematic. In other words, there is no major difference in driving the pylons into each of these sediments, as their characteristics are quite similar.

Air temperatures at 2 m above surface level are shown in Figure 4.4. The figure is based on hourly air temperature data from the 10-year period. The minimum and maximum air temperatures recorded in the ten-year period were -2.6 °C and 31.4 °C, respectively. Average air temperatures in the Veneto Region range from 16.3 °C to 16.7 °C, as shown in Figure 4.4. The average temperature for the whole region is 16.5 °C.

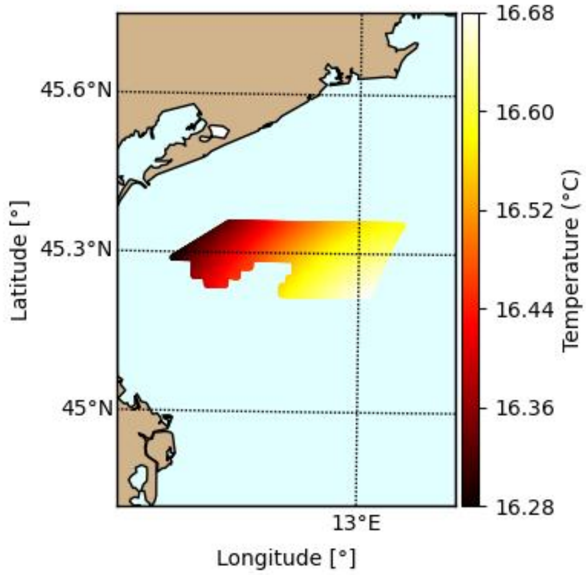


Figure 4.4. *Air temperature across the Veneto Region*

Other examined physical conditions are sea surface temperature and salinity. Figure 4.5 shows the 10-year average values across the Veneto Region. It is evident that the eastern and northeastern areas exhibit higher salinity and sea temperatures compared to the western side. In other words, the Po River carries cooler water to the western shore of Italy, which consequently results in a slightly lower salinity and temperature on that side of the Veneto region. Considering that values of salinity and temperature depend on the season, during summer it is expected higher salinity and temperature compared to winter. The minimum observed daily values of SST and salinity in the Veneto Region are 8 °C and 34 ppt, while the maxima are 30 °C and 38.5 ppt.

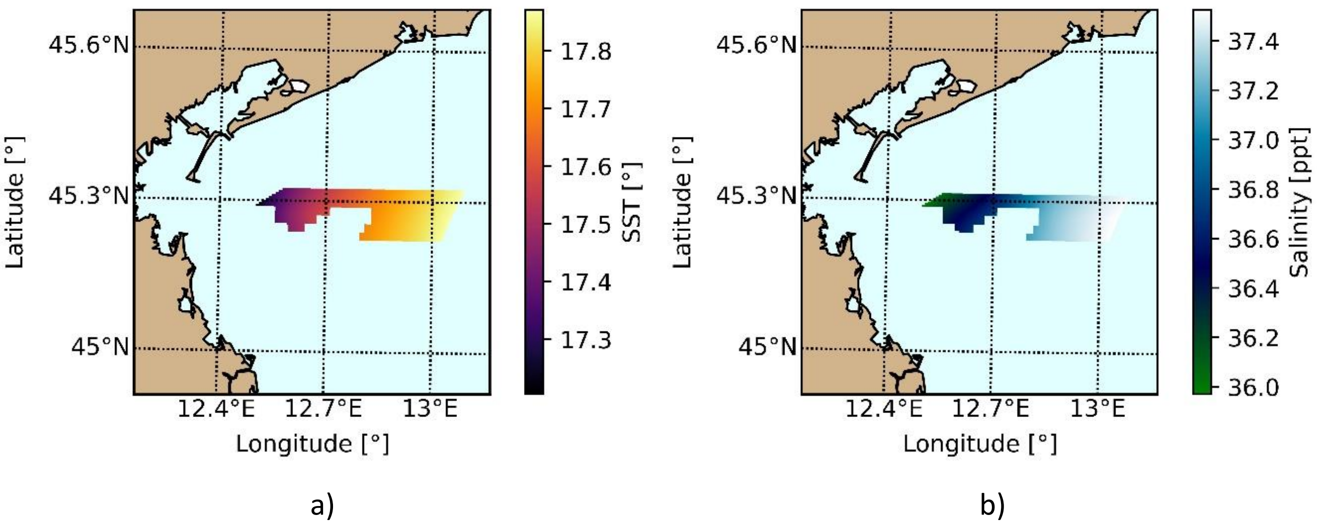
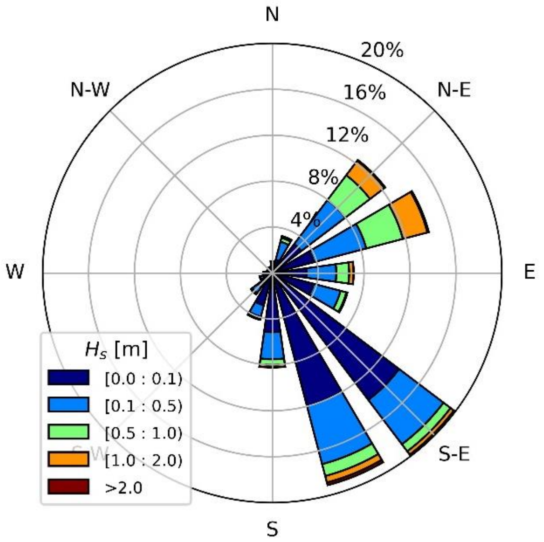


Figure 4.5. *a) Sea surface temperature and b) salinity across the Veneto Region*

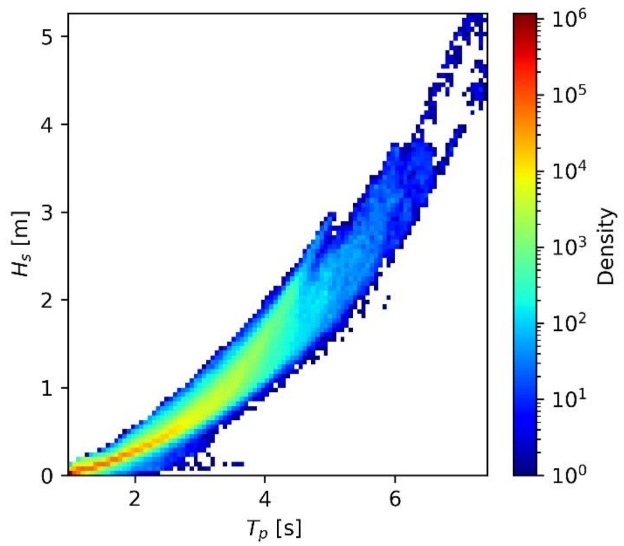
Veneto region has the highest changes in sea surface height compared to the other three pilot locations with an average value of -0.44 m. The minimum sea surface height above the geoid is -0.9 m while the maximum is 0.17 m.

Data of sea currents by depth for 10 years in the Veneto region has shown predominantly south and southwest directions of velocity, with magnitudes up to 0.2 m/s and average values of 0.04 m/s.

Figure 4.6 represents wave conditions at the Veneto region for hourly values for 10 years. From the wave rose diagram represented in Figure 4.6 a) it can be observed that most of the waves are coming from the southeast direction. Figure 4.6 b) represents the distribution density of values wave significant height (H_s) versus wave mean period (T_p). It can be observed that most of the time waves with small heights and short periods can be expected, with several extreme conditions. The highest observed value of wave significant height is 5.3 m, while the average value is 0.25 m.



a)



b)

Figure 4.6. *a) Wave rose and b) H_s/T_p density graph for Veneto Region*

4.2. Istria Region

Following the same procedure as for the Veneto region, the wind speed and its spatial distribution will first be analyzed for the Istria location, along with the creation of a wind rose for that area. Next, the bathymetry of the location will be examined, specifically focusing on water depth and seabed substrate. Additionally, other factors such as air temperature above the location, sea surface temperature, sea currents, sea salinity, and wave conditions will be analyzed for the same location.

4.2.1. Wind speed

Heat map of the average monthly wind speed for the period from 2009. to 2018. is shown in Figure 4.7. The trend of higher wind speeds in the winter months and lower values of wind speed in the summer months is even more emphasized in the Istrian region, than in the previously mentioned Veneto region (*Figure 4.1*).

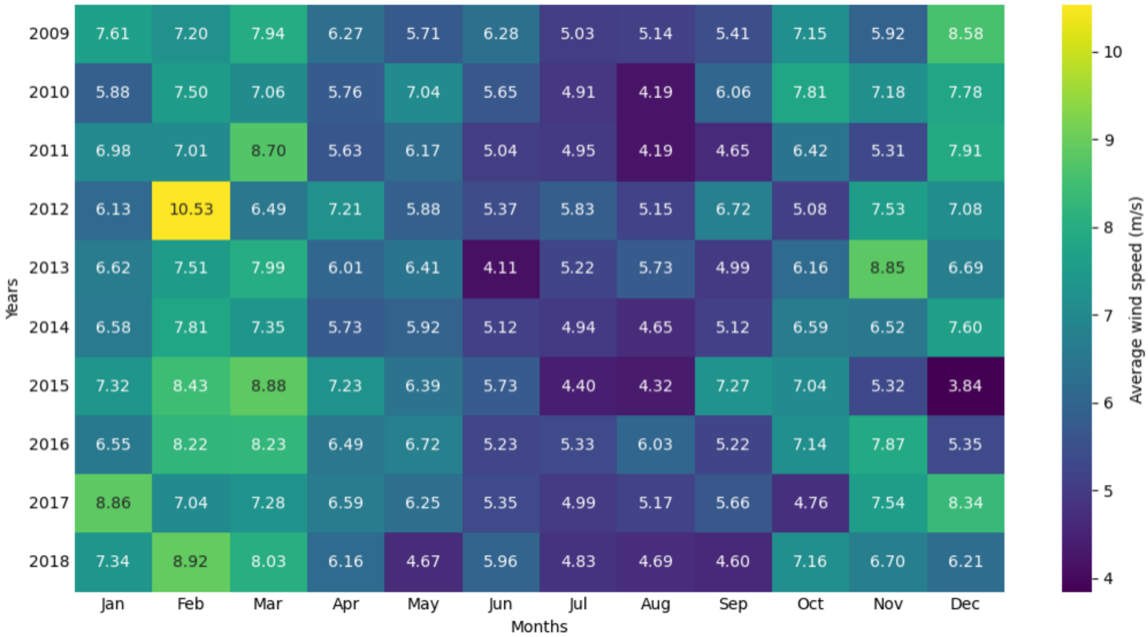
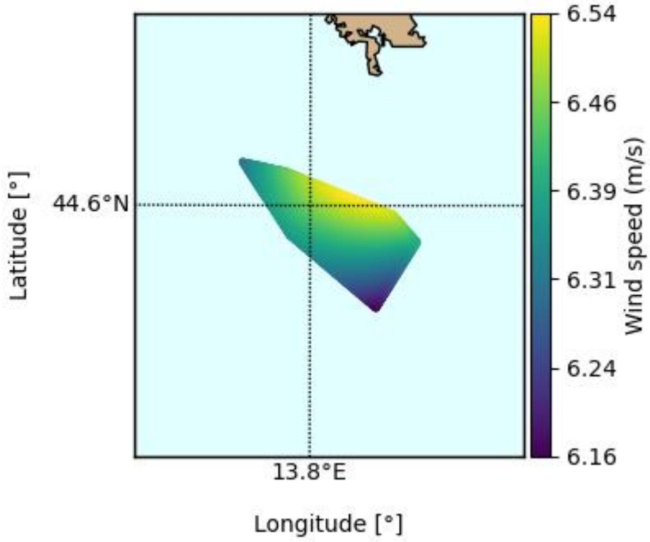
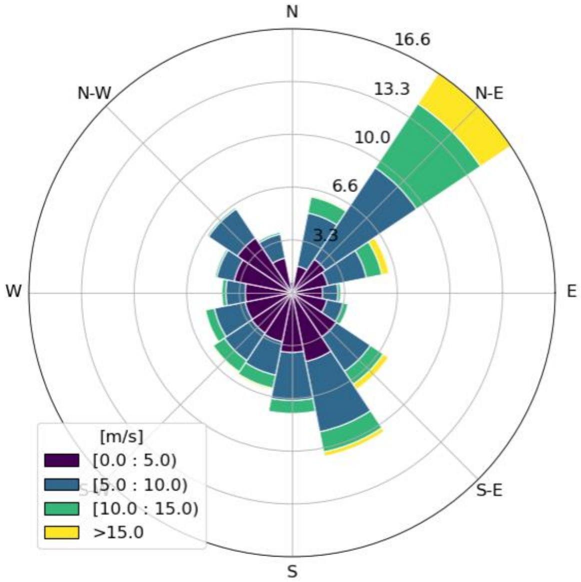


Figure 4.7. *Average monthly wind speeds at the Istrian Region for a period of 10 years*

Data on wind speed and direction for the Istria region were collected in the same manner as the Veneto region. The results of averaged wind speed over the polygon and direction are represented in Figure 4.8. In terms of spatial changes over location, the wind speeds vary from a minimum of just above 6.2 m/s in the southern part of the polygon to a maximum of 6.5 m/s in the northeast. The average wind speed value in the pilot area is calculated to be 6.4 m/s. The wind rose shows the spatial distribution of the wind above the Istria polygon, where the highest wind speeds come from the northeast and move diagonally towards the southwest.



a)



b)

Figure 4.8. *a) Averaged wind speed and b) wind rose for the Istria Region for a period of 10 years*

4.2.2. Water depth

The methodology for collecting bathymetry data for the Istria region follows the same approach as that used for the Veneto region. Figure 4.9 illustrates that the Istria region is characterized by shallow seas with a predominantly flat seafloor, with depths ranging from approximately -40 m to -50 m across an area of 220 km². The majority of the sea in this region, particularly in the northern and north-western parts of the polygon, has a similar depth of around -46 m. Additionally, at the centre of the region, there is a small circular hill that causes the shallowest sea depths in this area. The deepest areas within the Istria region are located in a narrow belt along the western part of the polygon, as well as in a small circular depression on the opposite side of the polygon.

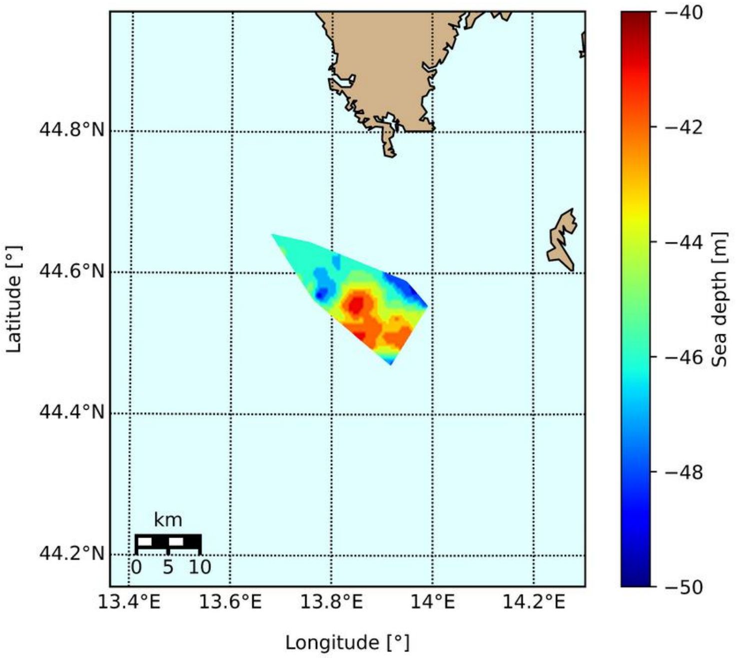


Figure 4.9. *Water depth across the Istria Region*

4.2.3. Additional factors

In this region, sand and silt cover and make up almost the entire seabed within the test polygon. Similar to the Veneto region, in the Istrian polygon, driving the foundations into the seafloor will also be possible and should not pose a significant challenge, as these sediments are present in sufficient thickness.

Figure 4.10 shows the air temperature over the Istrian Region at 2 m above sea level averaged over the 10-year period. The average air temperature at this pilot area is calculated to be 17 °C. and they range from 16.9 °C to 17.2 °C, as shown in Figure 4.10, with the difference between the highest and the lowest temperature being around 1.5%. Moving towards the southern part of the pilot area, a slight increase in the temperature can be observed. The minimum and maximum air temperatures recorded in the ten-year period were -1 °C and 30 °C, respectively.

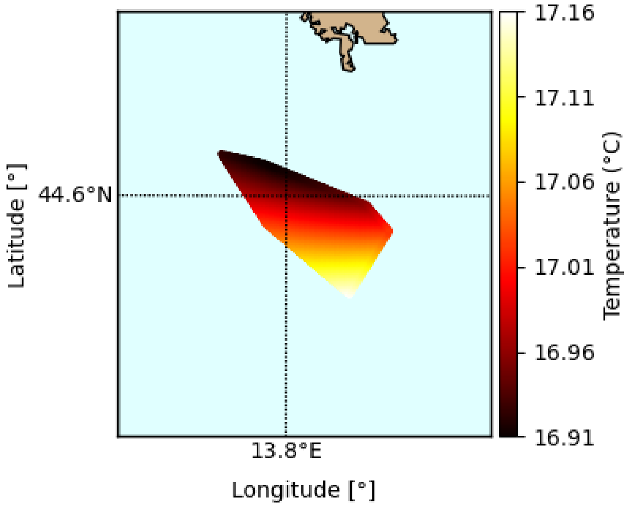


Figure 4.10. *Air temperature over the Istria Region*

Figure 4.11 represents averaged values of sea surface temperature and salinity for the 10-year period from 2013. to 2022. for the Istria test location. This salinity and sea temperature distribution is likely influenced by the Po River, which flows into the Adriatic Sea southwest of the observed location and brings the freshwater into the Adriatic. Therefore, the southwest part of a polygon has lower values of both variables. The minimum and maximum daily values of SST for the 10-year period are 10.5 °C and 28.9 °C, while for salinity it is 35.4 ppt and 39.1 ppt.

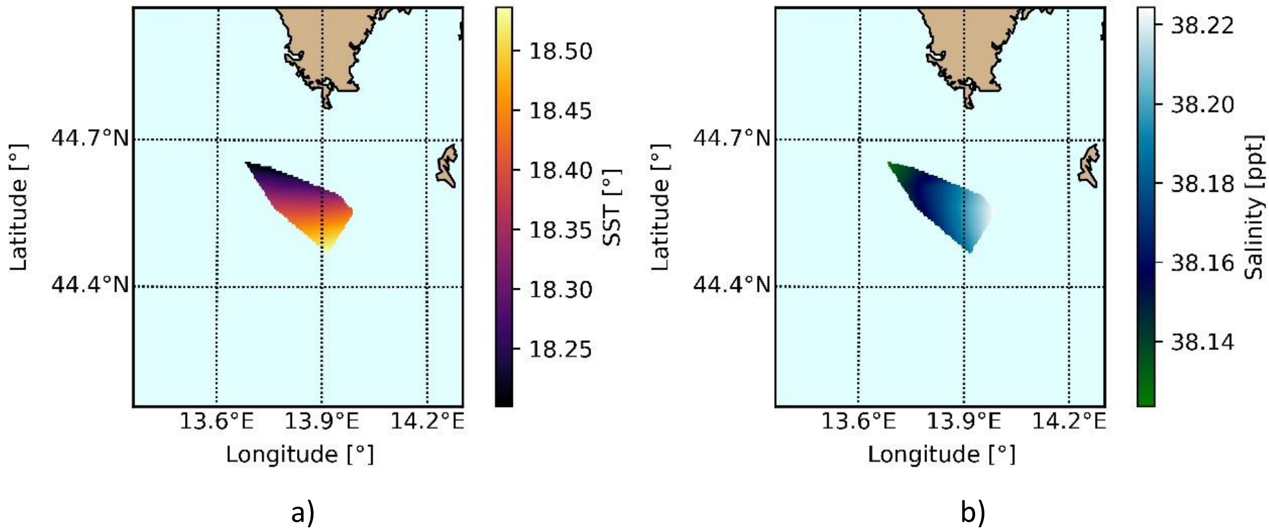
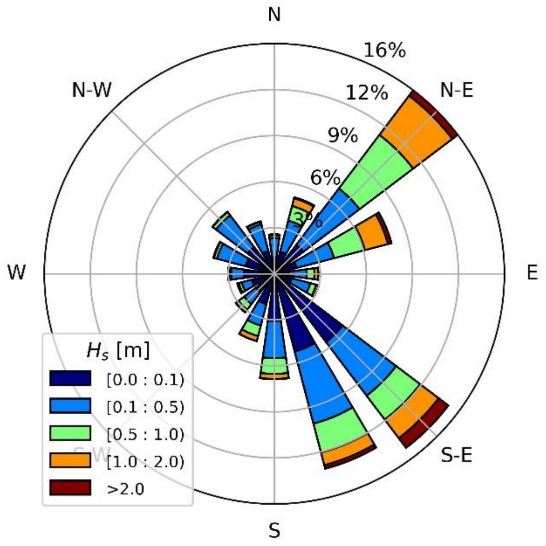


Figure 4.11. *a) Sea surface temperature and b) salinity across the Istria Region*

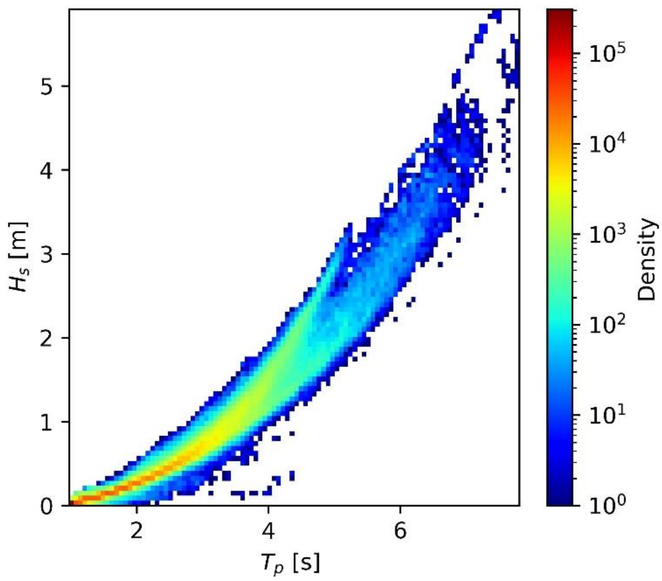
Changes in the sea surface height of the Istrian region were conducted for a 10-year period. The average value is -0.45 m with negligible changes over the region. Minimum values range from -0.89 m to 0.08 m above the geoid.

For the Istrian region, sea currents analysed for a 10-year period by depth showed a dominant direction in the south and southeast with maximum magnitudes of 0.5 m/s while averaged values were 0.03 m/s.

Wave conditions based on hourly value for 10 years can be observed in Figure 4.12. Figure a) represents the wave rose diagram which indicates that most waves are coming from north-east and south-east directions which are similar to the most frequent wind direction. From Figure 4.12 b) density diagram of wave significant height (H_s) versus wave mean period (T_p) similar wave conditions can be observed for the Veneto region, indicating that most of the waves have small heights and short wave mean periods. The maximum value of the wave significant height was 5.9 m, while the average value was 0.4 m.



a)



b)

Figure 4.1. *a) Wave rose and b) H_s/T_p density graph for Istria Region*

4.3. Split-Dalmatia County

As with the previous two locations, the same physical natural conditions will be analysed for the potential OWF installation site in Split-Dalmatia County. First, the wind speed and its spatial distribution will be examined, followed by the creation of a wind rose for the location. Using the same methodology as before, the bathymetry will be analysed, focusing on water depth and seabed substrate. Finally, additional physical factors such as air temperature above the location, sea surface temperature, sea currents, sea salinity, and wave conditions will be assessed.

4.3.1. Wind speed

Figure 4.13 shows average wind speeds for each month for the period between the years 2009 and 2018. Monthly average wind speeds can reach values as low as 3.6 m/s (August 2018.), which is unfavourable in terms of WT's power generation.

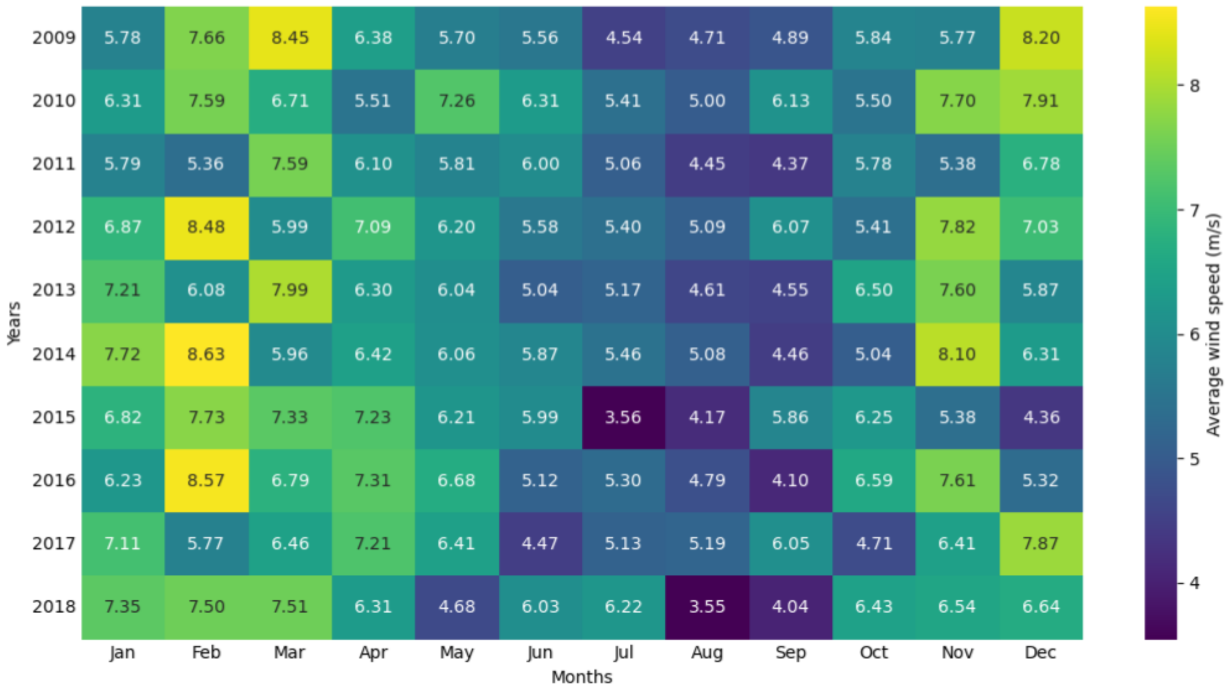
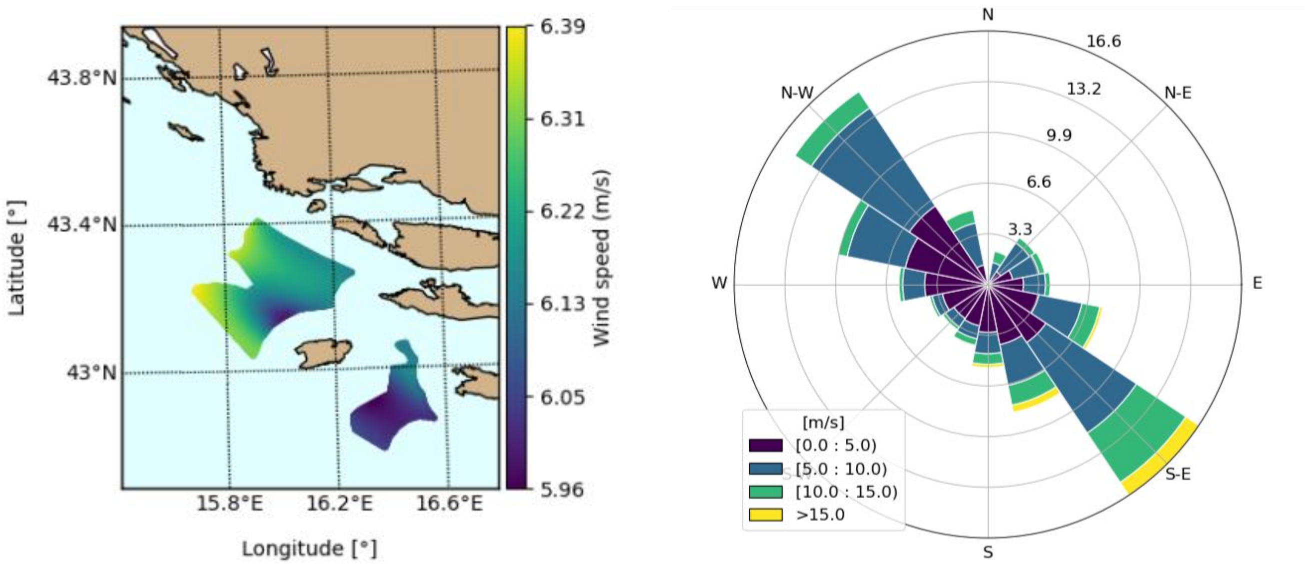


Figure 4.13. *Average monthly wind speeds at Split-Dalmatia County for a period of 10 years*

As for the previous cases, analysis of wind speed and direction is conducted for periods of 10 years with results for the Split-Dalmatia County pilot area presented in Figure 4.14. The minimum temporally average wind speed is 6 m/s, while the maximum temporally average wind speed is 6.4 m/s. Since the Split-Dalmatia County pilot area consists of 2 polygons, the wind rose represents averaged data on both areas. The wind is orientated parallel to the coast, therefore, the most common wind directions for Split-Dalmatia County are from the southeast and northwest.



a) b)

Figure 4.14. *a) Averaged wind speed and b) wind rose for the Split-Dalmatia County for a period of 10 years*

4.3.2. Water depth

From the collected bathymetry data for the two Split-Dalmatia test regions, it is evident that most of the seafloor in both areas has a depth of around or more than -100 meters (*Figure 4.15*). The deepest point in both polygons reaches -145 meters, while the shallowest point is approximately -65 meters. In the northern and larger test region, the predominant depth is around -125 meters. This northern area gradually deepens toward the northwest, whereas moving southeast, the seabed becomes shallower. Near the southern border of this polygon, there is a narrow strip where the depth slightly drops below -100 meters. However, the depth difference of around 45 m is equally distributed over an area of approximately 795 km^2. The southern Split-Dalmatia test region is slightly shallower and smaller in size. The deepest areas, located in the southwest, reach around -125 meters while moving northeast, the depth gradually decreases to the shallowest point of -65 meters. Similar to the northern polygon, the depth change is relatively gradual. The seafloor slope increases steadily toward the northeast and is fairly evenly distributed across the 275 km² area of the southern polygon.

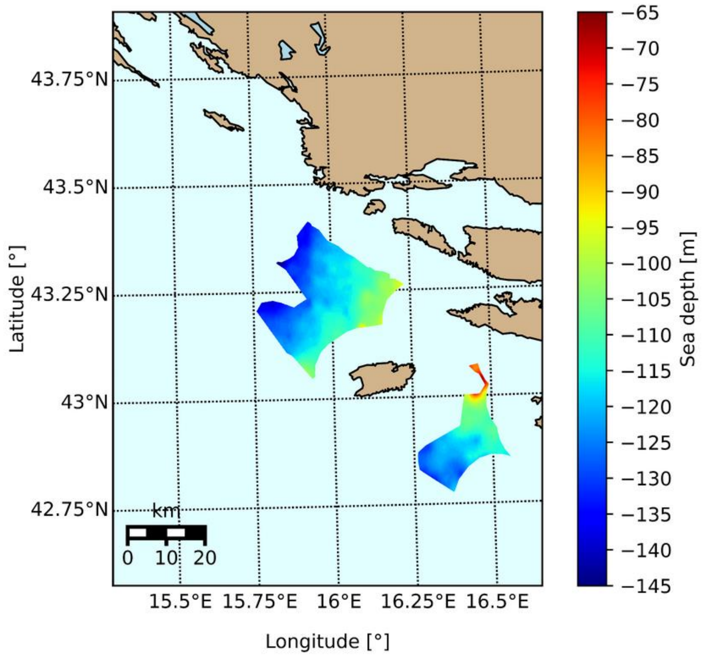


Figure 4.15. *Water depth across the Split-Dalmatia County*

4.3.3. Additional factors

In the Split-Dalmatia County test region, sediments such as sand, muddy sand, sandy mud, and silt are also present, similar to the Veneto region. However, there are also some rocks and boulders in smaller amounts. Additionally, in contrast to the two northern test regions, Veneto and Istria, the thickness of sediments in the Split-Dalmatia County region is not as considerable. Specifically, in the Split-Dalmatia County polygons, the sediments are not thick enough, with their thickness falling well below 70 m, particularly in the northern polygon where sediment thickness is very low. As a result, it will not be possible to drive foundations directly into the seafloor in these regions.

Air temperatures for the Split-Dalmatia County pilot area are presented in Figure 4.16. Shown values are temperatures at 2 m above sea level, also calculated as the average hourly values over the period of 10 years. Air temperature varies between 17.8 °C and 18.1 °C, with higher values occurring in the southern part of the pilot area. The minimum temperature in the 10-year period is –5.5 °C, the maximum value is 38.6 °C, and the average value is 17.9 °C.

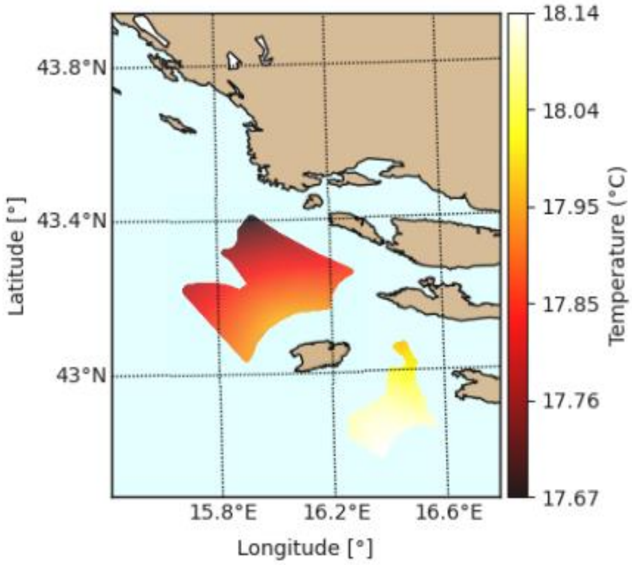
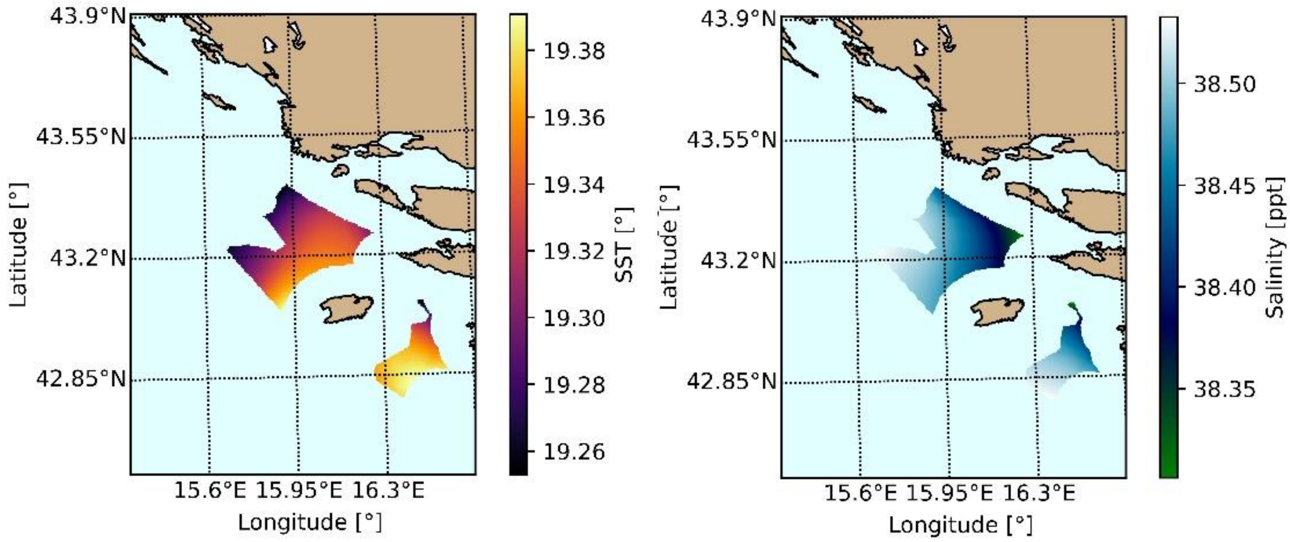


Figure 4.16. *Air temperature across the Split-Dalmatia County*

Results of 10-year average values of sea surface temperature and salinity across pilot regions in Split-Dalmatia County are presented in Figure 4.17. SST ranges from 19.3 °C in the northern part to 19.4 °C in the southern part of the pilot region. Lower salinity occurs on location near the coastline and ranges from 38.3 ppt to 38.5 ppt on the side close to the centre of the Adriatic Sea. Averaged values of SST and salinity for Split-Dalmatia County are higher compared to other two pilot regions. Minimum and maximum daily values for SST are 12.9 °C and 28.3 °C, while for salinity are 36.7 ppt and 39.2 ppt, resulting in smaller changes compared to the northern part of the Adriatic Sea.



a) b)

Figure 4.17. a) *Sea surface temperature and b) salinity across the Split-Dalmatia County*

The average value of sea surface height for Split-Dalmatia County is the same as for the Istrian region, with a value of -0.45 m. For 10 years period, minimum and maximum observed values were -0.85 and 0.02 m.

Sea currents analysis for 10 year period by depth in Split-Dalmatia county showed the highest values compared to other regions ranging up to 0.6 m/s in southeast and east directions. The average magnitude of sea currents was 0.06 m/s.

To analyse wave conditions in Split-Dalmatia Country, the wave rose diagram and density diagram of wave significant height (H_s) versus wave mean period (T_p) were represented in Figure 4.18 a) and b) based on hourly values of 10 years. The wind rose diagram indicates that the most frequent wave direction is similar to wind direction in the northwest and southeast directions. The H_s/T_p diagram indicates a slightly higher number of extreme events with higher significant height and longer mean period compared to the previous two regions which is expected due to the position in the Adriatic Sea. For the analysed region, the highest value of wave significant height was 5.6 m, while the average value was 0.42 m.

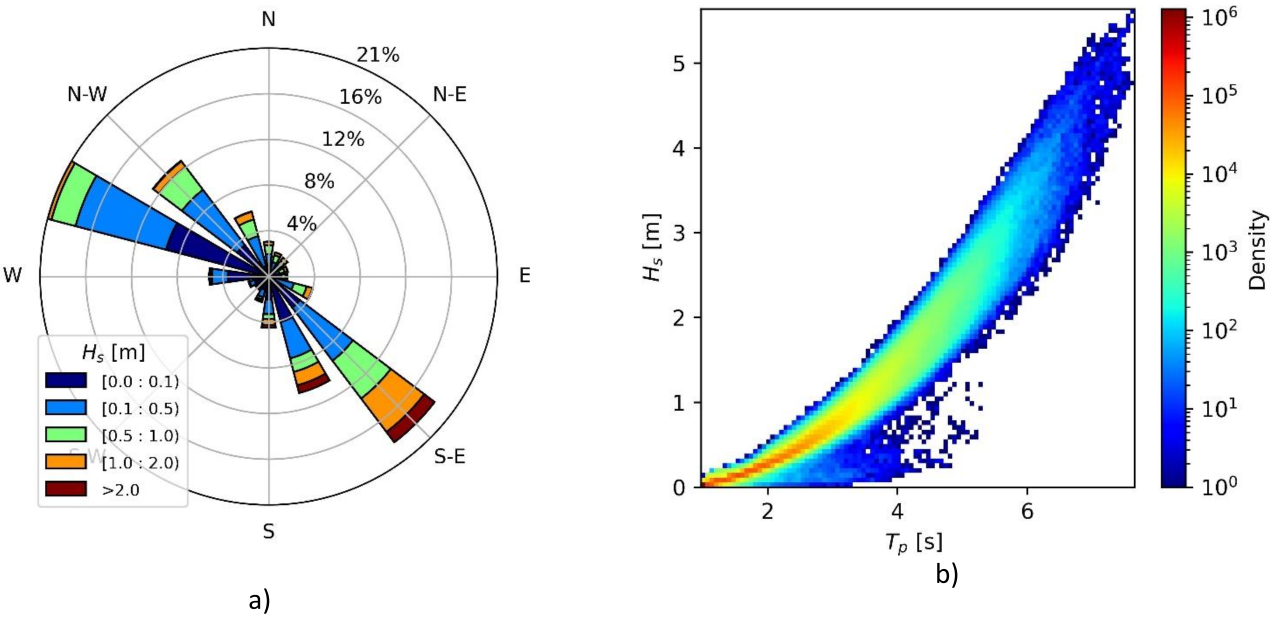


Figure 4.18. *a) Wave rose and b) H_s/T_p density graph for Split-Dalmatia County*

4.4. Apuglia Region

For the final of the four locations, the same physical natural factors will be analyzed using the same methodology. First, wind speed and its distribution over the location will be examined, followed by the creation of the wind rose. After the wind analysis, the bathymetry of the location will be assessed, specifically focusing on water depth and the seabed substrate. As with the previously mentioned locations, the additional physical factors such as air temperature above the location, sea surface temperature, sea currents, sea salinity, and wave conditions will be analyzed last.

4.4.1. Wind speed

Average wind speed values, for a specific month over the 10 year period, are shown in Figure 4.19. The trend of increasing wind speeds during the colder months can also be observed in this pilot area.

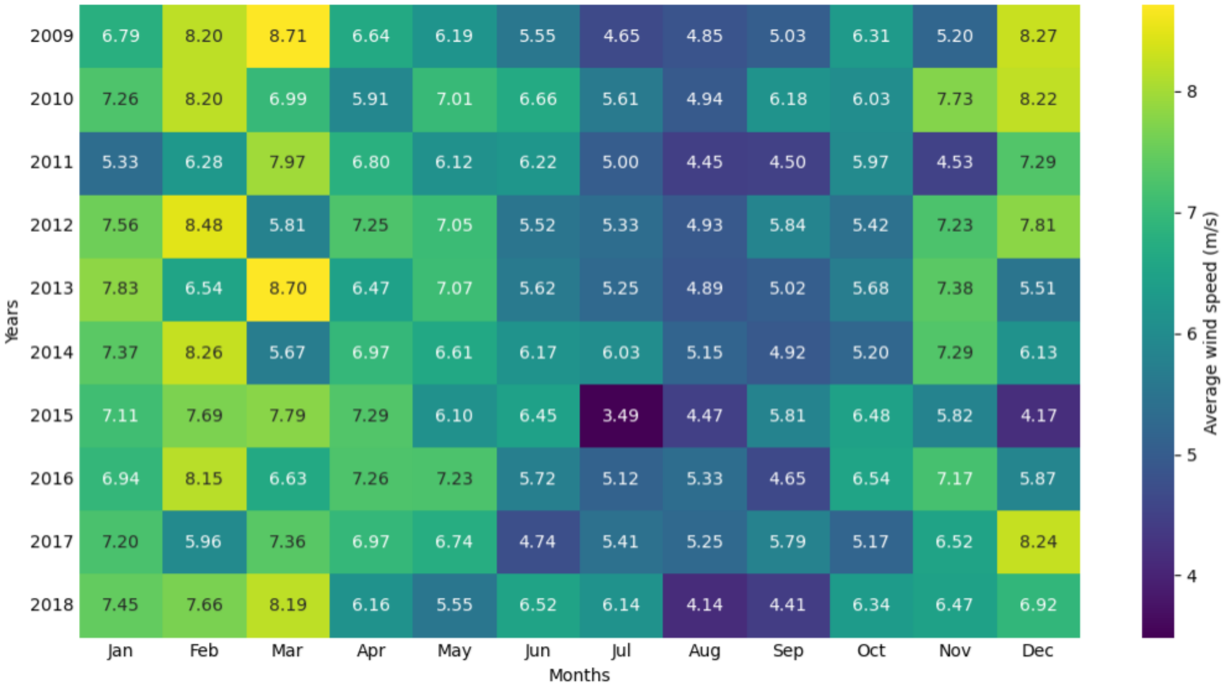
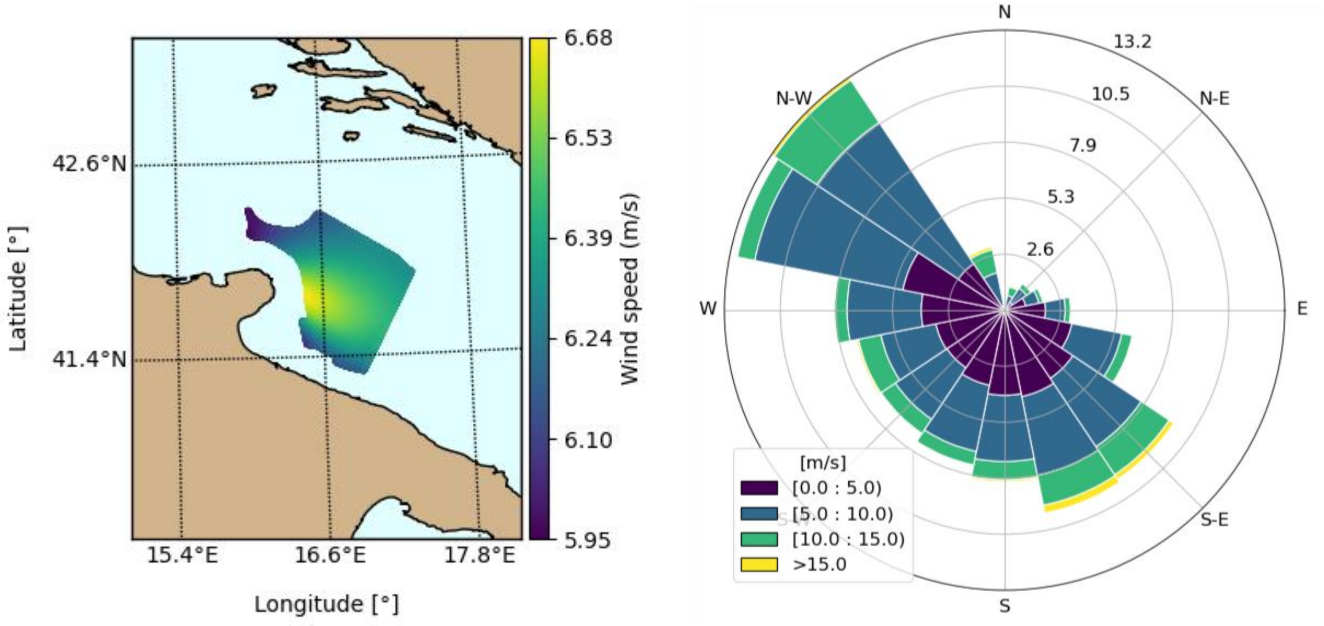


Figure 4.19. *Average monthly wind speeds at the Apuglia Region for a period of 10 years*

Average wind speed data and wind direction frequency, for the 10-year period, over the Apulia region pilot area, are shown in Figure 4.20. The minimum average calculated wind speed is 6 m/s, while the maximum average calculated wind speed is approximately 6.7 m/s, and the average value for this region is 6.4 m/s. Winds with the highest speeds occur from the southeast and from the northwest, with the most frequent wind directions appearing from northwest direction.



a) b)

Figure 4.20. *a) Averaged wind speed and b) wind rose for the Apuglia Region for a period of 10 years*

4.4.2. Water depth

The Apulia test region has the deepest waters among all test sites in the Adriatic. Bathymetric data for the three Apulia polygons show that the deepest point reaches just below -1000 m, while the shallowest point is approximately -50 m (F*igure 4.21*), which represents a significant difference in water depth. The shallowest waters are found along a strip between the northwest border of the Apulia region and an imaginary diagonal line running parallel to this border, effectively dividing the area in half. In this section, the sea depth ranges from -55 m to around -140 m, with a relatively flat seafloor and minimal depth variation, distributed uniformly across an area of approximately 2790 km². Moving southeast beyond this dividing line, the seafloor slope begins to drop sharply, causing the depth to increase rapidly from -140 m to around -1000 m. This means the southeastern half of the Apulia region is very steep. Additionally, this dividing line mainly follows the boundary of the South Adriatic Basin, where the Adriatic Sea begins to deepen significantly toward its deepest point.

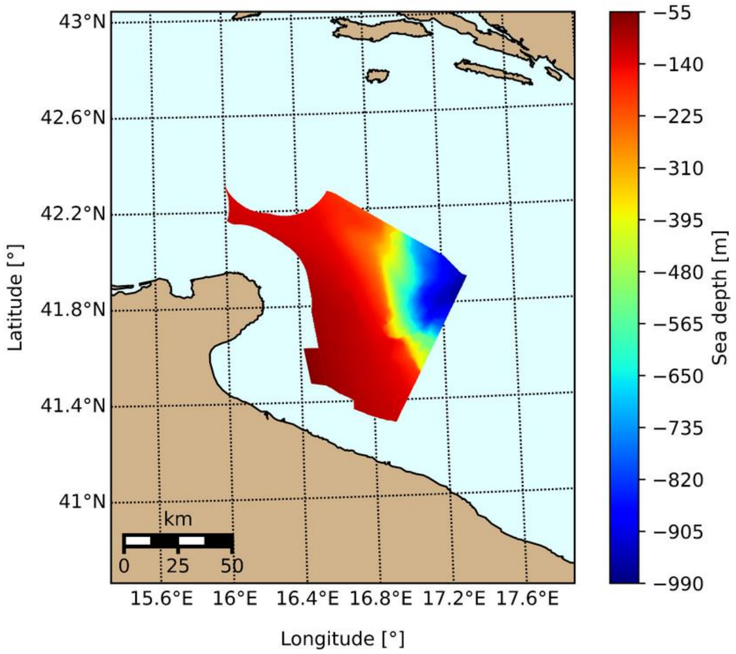


Figure 4.21. *Water depth across the Apuglia Region*

4.4.3. Additional factors

The seabed of the Apulia region consists of sand, mud, sandy mud, and silt. The thickness of these sediments is predominantly above 100 m. This means that in these testing polygons, it will be possible to directly drive the foundations, and the type of seabed will not pose a significant problem if a direct-driven foundation is chosen.

Air temperatures, at 2 m above sea level and averaged over the 10-year period, over the Apulia region pilot area are shown in Figure 4.22. Temperatures in the eastern part of the pilot area are higher, with values being 17.9 °C and reaching up to 18.2 °C. The minimum temperature in the 10-year period is –7.3 °C, the maximum value is 43 °C, and the average value is 18 °C.

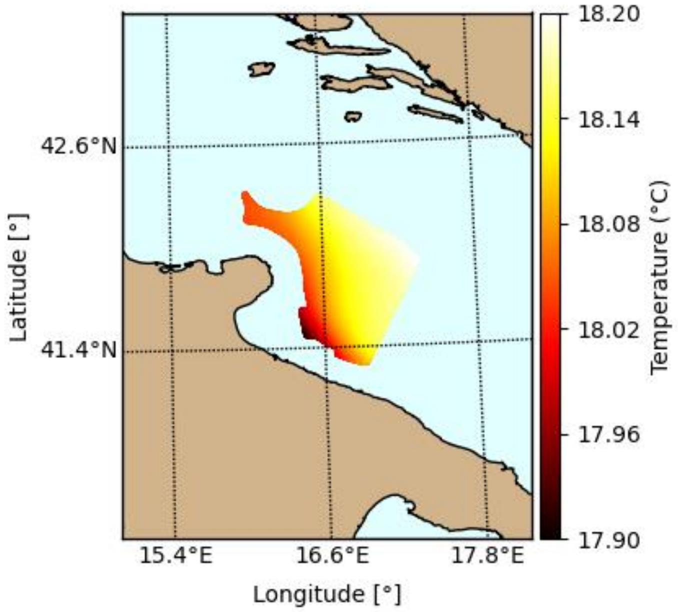


Figure 4.22. *Air temperature across the Apuglia Region*

Figure 4.23 represents 10-year average values of sea surface temperature and salinity across the Apuglia Region. Lower values of SST and salinity can be observed in part of the region close to the coast, while regions away from the coast have higher values. Similar to Split-Dalmatia County lower averaged values can be observed compared to test cases in the northern part of the Adriatic Sea. Daily values of SST for 10 years range from 12.6 °C to 28.6 °C, while for salinity from 36.8 to 39.1 ppt.

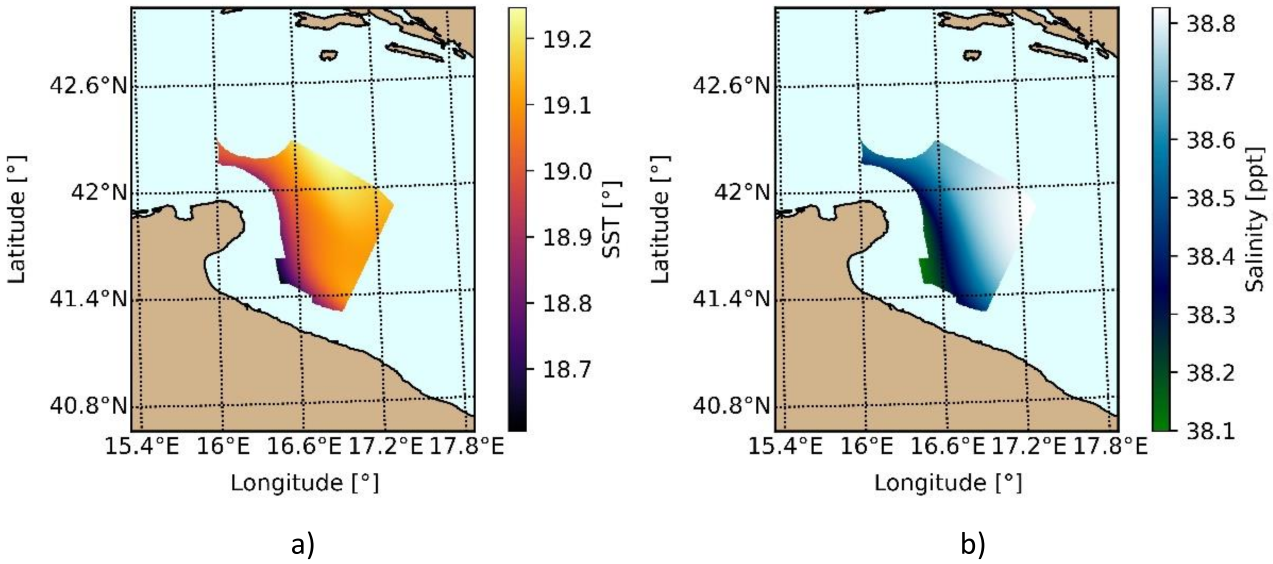
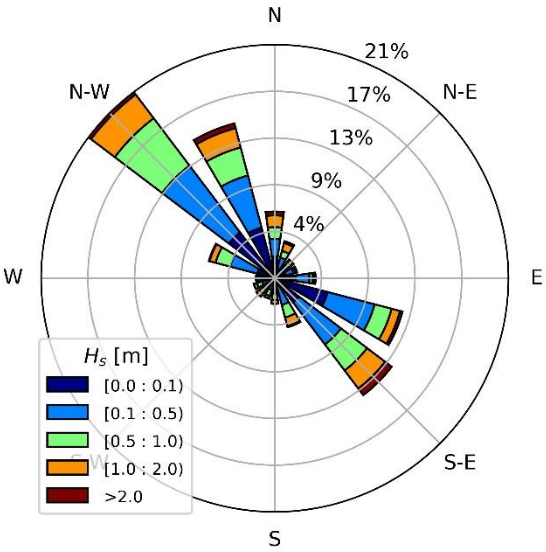


Figure 4.23. *a) Sea surface temperature and b) salinity across the Apuglia Region*

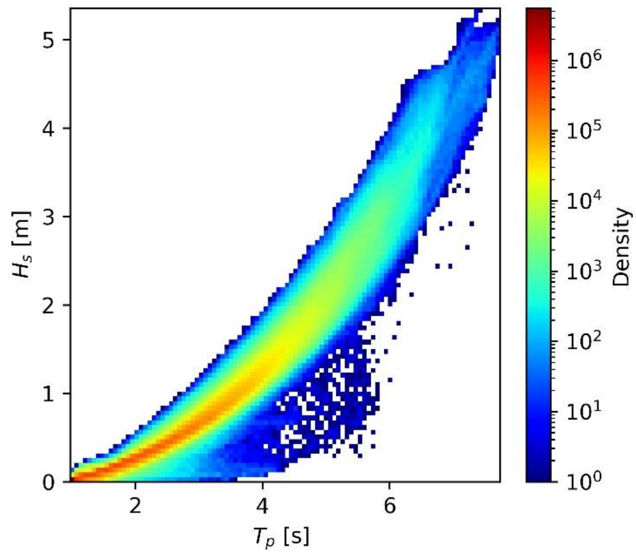
In the Apuglia region, the lowest average sea surface height is observed with a value of -0.48 m. In an analyzed 10-year period, values of sea surface height above the geoid range from -0.85 to 0 m.

Analyses of sea currents for 10 years in the Apuglia region show a dominant west direction of currents with maximum values of magnitudes up to 0.4 m/s and average value of 0.01 m/s.

Wave conditions for the Apuglia region are presented in Figure 4.24 based on hourly 10 years values. Figure a) of the wave rose diagram indicates the most dominant direction of waves is northwest. The density diagram of wave significant height (H_s) versus wave mean period (T_p) indicates a larger number of events with higher significant height and especially a longer mean period compared to other regions. This suggests that more focus on offshore foundations should be considered for this region because it will be more often loaded with extreme wave conditions. The highest value of wave significant height for the Apuglia region was 5.35 m, while the average value was 0.48 m.



a)



b)

Figure 4.24. *a) Wave rose and b) H_s/T_p density graph for Apuglia Region*

5. Joint summary and recommendations

This report examines two key natural factors that significantly impact OWF installation and energy production, namely wind conditions and water depth. From wind analyses, lower wind speed in each of the four locations can be observed, compared to the usual design wind speed of OWFs. However, these wind speeds are fairly consistent throughout the year, which is a positive aspect, as there are no significant deviations, allowing the OWF to operate under nearly identical conditions most of the time. Additionally, the changes in available wind speed are quite similar across all four locations, with only minor variations. This indicates similar wind potential for all pilot locations with comparable characteristics regarding wind conditions at each location.

In contrast, water depths at each location vary. The conducted analysis demonstrated that the two northern locations in the Adriatic Sea have shallower waters with minimal depth variation within each location and between the two. In other words, the water depths in these locations are suitable for installing OWFs with fixed foundations into the seafloor. However, in the two southern locations, the sea is deeper, with more significant changes in water depths within each location, particularly in the Apuglia region. The water depths in these two southern regions mostly fall outside the range for OWF installation of fixed foundation and require floating foundation types.

Additionally, several other natural factors are examined, including seabed substrate type, seismic hazard zones, air and sea surface temperature, salinity, sea currents, sea surface height, and wave conditions. Analyss of hazard zones identified that there is no significant risk for OWFs operation. For air and sea surface temperature, salinity, sea currents, sea surface height, and wave conditions minimum and maximum expected variables values were identified to establish operational range of OWFs which needs to be taken into consideration for identifying appropriate technical solution.

It must be noted that findings presented in this report contain preliminary analysis based on the freely available data, which is often based on lower resolution data based on approximations or simulated results. To ensure the data and analysis results are as accurate as possible, it is necessary to measure the data directly at the chosen test locations or take and analyze samples in-situ, where possible (e.g., seabed substrate and sea salinity).

6. Literature

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