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PROGRAMME 2021 – 2027

BEYOND - Blue Economy sYnergies fOr sustainable Development

D.3.2.2 Cross-sectorial programme learning material

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Contributors:	Simone Libralato, Sophie Burton Pogledic, Stefan Ivić, Martina Ivić, Matej Mališa, Zvonimir Mrle, Marta Alvir		

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Contents

1.	Introduction.....	4
2.	Learning Objectives and Assessment Methods	5
3.	Module Descriptions and Resource Lists.....	7
4.	Learning Materials.....	10
4.1.	Module 1: Offshore Wind Farms	10
4.2.	Module 2: Fluid Mechanics of Wind Turbines	13
4.3.	Module 3: Physical Conditions and Wind Potential for Offshore Wind Farms in the Adriatic.....	15
4.4.	Module 4: Offshore Wind Farm Layout Optimization	18
4.5.	Module 5: Wind Turbine Airfoils.....	19
4.6.	Module 6: Offshore Wind Turbines Foundation Types	21
4.7.	Module 7: Application of CFD for offshore wind farms	23
4.8.	Module 8: The Need for Green Energy Production and the Potential of Marine Renewable Energy.....	25
4.9.	Module 9: OWF and Interactions with the Fisheries Sector	27
4.10.	Module 10: Geohazards and OWFs.....	30
4.11.	Module 11: Ecological-Acoustic Impacts of Infrastructures at Sea	31
4.12.	Module 12: The Role of MSP for the Sustainable Development of Offshore Wind Farms.....	34
4.13.	Module 13: Planning an Offshore Windfarm, Compensation Activities and Valorisation.....	36
4.14.	Module 14: Ecosystem Approach for Analysis of Cumulative Impacts of Offshore Wind Farms.....	37
4.	Conclusion	39



1. Introduction

To assure the long-term sustainability of the Cross-Sectorial Education Program, a detailed syllabus has been developed to further elaborate on D3.2.1 Cross-Sectorial Education Program Curriculum, as a blueprint for teachers and future students to understand the rigors and final expectations of the learning journey. Here, learning objectives and assessment methods will be explored as well as module descriptions and resource lists, which provide the backbone of the Cross-Sectorial Education Program syllabus. The development of a detailed syllabus is essential for any student who wants to deepen their understanding of the technical and environmental aspects of offshore wind farm (OWF) development as it provides them with a document to refer to, while ensures they remain focused on the objectives of their learning.

The Cross-Sectorial Education Program syllabus is divided into 14 modules between two core pillars: technical and environmental, each encapsulating seven modules. To ensure the syllabus delivers a comprehensive overview of OWF development, a variety of learning materials have been selected along with teachers who are able to engage students in multiple ways, using lectures, graphics, demonstrations, case studies and hands-on activities through active and scaffold learning.



2. Learning Objectives and Assessment Methods

Upon successful completion of this course, students will have acquired the knowledge and skills necessary to analyze offshore wind energy systems from both engineering and environmental perspectives, including the assessment of their technical performance, environmental impacts, and interactions with marine ecosystems. Specifically, students will be able to:

1. Explain the current status of offshore wind farms and their role in the renewable energy sector, wind turbine components, and operational characteristics.
2. Apply the principles of fluid mechanics and atmospheric boundary layer theory to analyse wind flow and its influence on offshore wind turbine performance.
3. Assess physical conditions influencing offshore wind energy, with particular emphasis on the Adriatic Sea.
4. Evaluate and optimise offshore wind farm layouts by considering wake effects, energy production and economic factors.
5. Analyse the aerodynamic characteristics of wind turbine airfoils and their influence on turbine efficiency and power generation.
6. Compare and select appropriate offshore wind turbine foundation types based on site-specific, hydrodynamic, and structural requirements.
7. Apply Computational Fluid Dynamics (CFD) methods to simulate and analyse fluid flow around offshore wind farms, and interpret simulation results to support engineering design.
8. Understand and identify the challenges, opportunities and solutions regarding interactions between OWF and the fisheries sector;
9. Understand the role of Marine Spatial Planning (MSP) for the sustainable development of OWF;
10. Understand the importance of Nature Inclusive Design (NID) and OWF;
11. Understand the ecological impact of OWF infrastructures at sea and how to interpret results;
12. provide a comprehensive general introduction to the assessment and mitigation of acoustic impacts associated with offshore wind energy development;



13. Explain the geohazards and their potential interactions with OWF;

14. Apply skills acquired through practical use of an ecosystem model representing effects of OWF.

Assessment methods are designed to evaluate students' understanding of engineering principles, environmental processes, and their ability to integrate technical and ecological considerations in offshore wind farm planning and design. Students' achievement of the learning outcomes will be assessed through a combination of continuous assessment and a final examination:

- Homework assignments – 20%
- Midterm examination – 30%
- Group project and presentation – 20%
- Final examination – 30%



3. Module Descriptions and Resource Lists

The module structure integrates engineering, environmental, and sustainability perspectives to provide students with a comprehensive understanding of offshore wind energy systems. The course will include 14 modules that are roughly divided into two pillars: the Technical pillar exploring more technological and mechanical aspects through 7 modules; the Environmental pillar in which explored ecological aspects and ecosystem approach through 7 modules. Titles and descriptions of the 14 modules are as follows:

Technical Pillar

Module 1: Offshore Wind Farms – This module provides an overview of offshore wind farms, their role in the renewable energy transition, and the current state of the industry. It covers the current development of the offshore wind industry, the main components of wind turbines, and the operational characteristics of offshore wind energy systems.

Module 2: Fluid Mechanics of Wind Turbines – This module introduces the principles of fluid mechanics governing wind flow and their application to wind turbine aerodynamics. Topics include logarithmic wind profiles, air and sea properties, and an assessment of the influence on energy production and offshore wind farm operation.

Module 3: Physical Conditions and Wind Potential for Offshore Wind Farms in the Adriatic – This module examines the physical conditions that influence offshore wind energy development in the Adriatic Sea. The module also presents a simple grid layout approach for wind turbine micro-siting as an introductory method for the preliminary design of offshore wind farms.

Module 4: Offshore Wind Farm Layout Optimisation – This module introduces the principles and methods used to optimize offshore wind farm layouts to maximise energy production and minimise levelized cost of energy. Topics include wake effects, optimisation methods, site constraints, and the integration of technical, economic, and environmental considerations.

Module 5: Wind Turbine Airfoils – In this module, fundamental principles of wind turbine airfoil design will be introduced. Students will examine the geometry and aerodynamic characteristics of airfoils,



including lift, drag, and stall, and evaluate their influence on wind turbine performance and energy production.

Module 6: Offshore Wind Turbines Foundation Types – This module provides an overview of the main offshore wind turbine foundation types, their application, and selection based on site-specific conditions.

Module 7: Application of CFD for offshore wind farms – This module introduces the application of Computational Fluid Dynamics (CFD) to the analysis and design of offshore wind farms. Students will learn fundamentals of CFD and numerical modelling, including mesh generation, boundary conditions, and turbulence models, and apply these techniques to simulate flow around offshore wind farms.

Environmental Pillar

Module 8: The Need for Green Energy Production and the Potential of Marine Renewable Energy – this module provides an overview of the energy transition process with a particular focus on the opportunities and challenges faced by coastal regions. Using examples from the Adriatic Sea and the Region of Istria (Croatia), the content examines the role that marine renewable energy technologies may play in supporting future energy systems. Particular attention is given to offshore wind energy, seawater-source heat pumps, floating photovoltaic systems, and other innovative solutions that can contribute to decarbonisation while respecting environmental and spatial constraints.

Module 9: OWF and Interactions with the Fisheries Sector – this module will focus on challenges, opportunities and solutions with particular emphasis on the main operational, ecological, and governance challenges associated with the coexistence of OWFs and the fisheries sector. The content will then assess the potential impact of OWF development on fisheries and aquaculture, which presents an integrated framework combining four complementary levels of analysis to evaluate these interactions in the Adriatic Sea.

Module 10: Geohazards and OWFs -this module provides an overview of the main marine geohazards relevant to offshore wind development, including active faulting and earthquakes, submarine landslides and canyon instability, tsunamis, shallow gas and fluid flow, scour, sediment mobility and liquefaction. Particular attention is given to the Mediterranean, where active tectonics, steep



continental margins, high seismicity and dynamic sedimentary processes create a combination of hazards that differs substantially from those encountered in the North Sea.

Module 11: Ecological-Acoustic Impacts of Infrastructures at Sea – this module explores how the rapid expansion of offshore wind energy in the global transition to renewable energy has contributed to potential geohazards, and ecological impacts at sea, as well as introduced new sources of underwater noise that may affect marine ecosystems.

Module 12: The Role of MSP for the Sustainable Development of Offshore Wind Farms –This module will look at how Maritime Spatial Planning (MSP) is not an end in itself, but a practical way to create and establish a more rational use of the marine space and the interactions among its uses, to balance demands for development with the need to protect the environment, and to deliver social and economic outcomes in an open and planned way. The module will then present practical examples of OWF zoning in Italian case studies.

Module 13: Planning an Offshore Windfarm, Compensation Activities and Valorisation – this module provides a real-life case study e.g. Rimini Project 2020, focusing on the works carried out on land and sea, and also features solutions for interaction with other Blue Sectors Including Nature Inclusive Design (NID)

Module 14: Ecosystem Approach for Analysis of Cumulative Impacts of Offshore Wind Farms – this module explores a holistic approach to evaluating the ecosystem-wide and socio-economic consequences of OWF developments, including the practical use of an ecosystem model representing the effects of OWF (simplified use).

The course resource list consists of textbooks, technical standards, and online resources that support students' learning throughout the course. The selected materials reflect both the engineering and environmental perspectives of offshore wind energy.

Software:

- Ansys
- Python



- R scripts and RStudio
- Ecopath with Ecosim

Technical Standards and Reports:

- IEC 61400 series
- DNV-ST-0126
- DNV-ST-0119

Online Resources:

- European Marine Observation and Data Network (EMODnet) (<https://emodnet.ec.europa.eu/>)
- Copernicus Marine Service (CMS; <https://marine.copernicus.eu/>)
- Global Wind Atlas
- European Wind Atlas

4. Learning Materials

The learning materials present here represent a shortened description of the modules covered in the course. They serve as a supporting resource for students and complement the more detailed explanations, discussions, and practical activities provided throughout the course.

4.1. Module 1: Offshore Wind Farms

Rapid growth in global energy demand due to global population growth and civilisation advances causes an increase in greenhouse gas emissions and rapid progression of climate change. To deal with this problem, renewable energy is becoming crucial. Although renewable onshore energy is cheaper, easier to deploy, and has a much larger installed base, renewable offshore energy is crucial to the large-scale, long-term energy transition. Renewable offshore energy includes several different types of technologies: offshore wind, wave power, tidal power, floating solar and thermal energy. The EU Strategy for Offshore Renewable Energy by the European Commission aims to reach 61 GW from offshore renewable energy by 2030 in the European Union, and 340 GW by 2050. To achieve those goals, renewable offshore wind



energy is the present most promising technology for large-scale electricity generation. Main benefits are strong and relatively consistent wind resources available at sea, the ability to install very large turbines and wind farms in a large available marine area. An offshore wind farm is presented in Figure 4.1.



Figure 4.1. Offshore Wind Farms. Source: © WindEurope. Reproduced in accordance with WindEurope's website terms.

Currently, cumulative installed global offshore wind capacity is 92.5 GW (Global Wind Report 2026). China is the global leader, accounting for 52% of the world market for offshore wind energy. United Kingdom is second globally and first in Europe, with 18.4% of the world market. The current status of offshore wind farms in Europe is shown in Figure 4.2. It can be observed that most offshore wind farms are located in the North Sea and Baltic Sea due to shallow waters and strong, consistent winds. Mediterranean and Adriatic Seas have deep water relatively close to shore, which makes investments more expensive; therefore, there are only a few smaller locations of offshore wind farms.

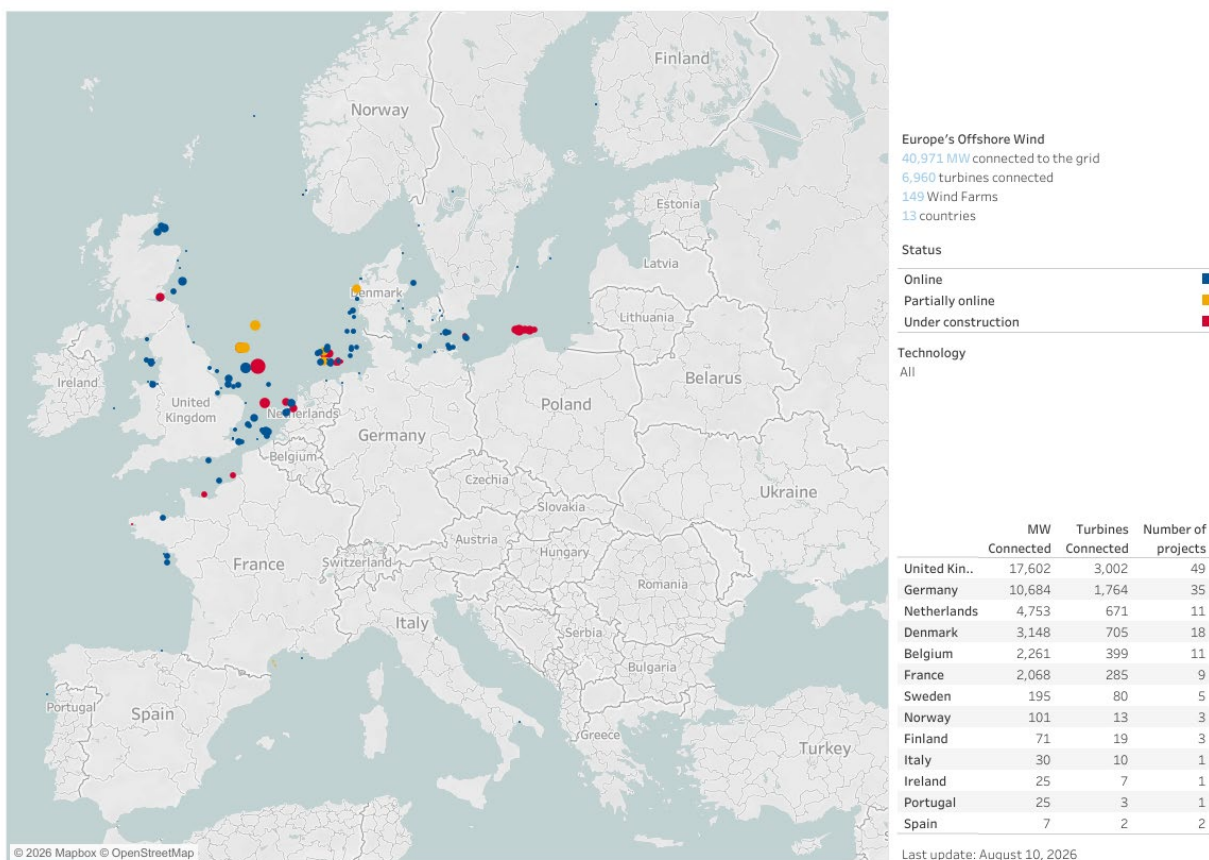


Figure 4.2. Current status of offshore wind energy in Europe. Source:

<https://windeurope.org/data/products/european-offshore-wind-farms-map-public/>

An offshore wind farm is an integrated system that generates, collects, transforms, and transmits electricity to the onshore electricity grid. It consists of several main parts. Offshore wind turbines convert wind kinetic energy into electrical energy. Foundations and support structures are used to support the turbine and transfer loads to the seabed or mooring system. An offshore substation collects electricity from the turbines and transmits the power to the onshore grid. Inter-array and export cables are subsea electrical cables used to connect individual wind turbines and the offshore substation toward the coast. Main parts of an offshore wind turbine are: rotor (consists of blades and hub), nacelle (consists of



machinery used to convert rotor rotation into electricity), tower (supports the rotor and nacelle), support structure/foundation (connects the turbine to the seabed).

4.2. Module 2: Fluid Mechanics of Wind Turbines

For analysis of the design, performance, and reliability of offshore wind turbine farms, it is fundamental to know the basics of fluid mechanics because wind turbines operate entirely within fluids: the air and the sea. Understanding how air and water flow around turbines and support structures determines how much energy can be produced, how long the structures last, what the most optimal solutions are, and how safe and economical the farm will be.

One of the main parameters that determines the behaviour of fluid flow around offshore wind farms is the Reynolds number, which can be described with the equation presented in Figure 4.3. High fluid speeds and large dimensions of offshore wind farms produce extremely high Reynolds numbers, therefore inertial forces dominate over viscous forces, causing the flow to become highly turbulent.

$$Re = \frac{\rho v l}{\mu}$$

or

$$Re = \frac{v l}{\nu}$$

Where:

- ρ – The density of the fluid
- v – Speed of the fluid [m/s]
- l – The characteristics length
- μ – The dynamic viscosity of the fluid
- ν – The kinematic viscosity of the fluid

Figure 4.3. Reynolds number.

Electricity from wind turbines is generated by converting the kinetic energy of moving air into rotational mechanical energy. Produced wind power can be calculated using the formula in Figure 4.4. The rotor swept area is the circular area covered by the rotating wind-turbine blades as they spin, and it can be calculated as the area of a circle with a radius which is equal to the wind turbine blades.



$$P_{wind} = \frac{1}{2} \cdot \rho \cdot v^3 \cdot A$$

Where:

ρ – air density

v – wind speed

A – rotor swept area

Figure 4.4. Theoretical wind power equation.

Air properties determine how much power can be generated, how loads act on the turbine, and how efficiently the wind farm will operate. The main air properties are wind speed, density, temperature, pressure, humidity, and turbulence. Many of these air parameters are interconnected and influence one another. For example, when the temperature increases, air expands, while higher atmospheric pressure compresses air. Wind speed is the most important factor in wind energy production.

Main seawater properties that should be considered when planning offshore wind farms are salinity, density, temperature, pressure, sea currents, sea surface height, waves and marine growth. These properties affect structural stability, loading, corrosion, maintenance, and the overall lifetime of the offshore wind farm.

The Atmospheric Boundary Layer (ABL) or Planetary Boundary Layer (PBL) is the lowest part of the atmosphere that is directly influenced by the Earth's surface through heat transfer, moisture exchange, friction and terrain or sea conditions. It can be divided into 3 zones: the Surface Layer close to the Earth, the Mixed Layer and the Entrainment Zone. Depending on the weather and conditions on the surface, ABL typically extends from 200 meters up to about 2 kilometres in altitude. One of the most important characteristics of ABL is the wind gradient, which determines the change in wind speed with height, caused mainly by surface friction. On the ground, the speed of the wind is zero (no-slip condition) and increases with increasing altitude. In Figure 4.5, the equation for the wind profile power law is presented.



Where:

$u(z)$ - wind speed at height z

u_{ref} - measured wind speed at height z_{ref}

α – Hellman (power-law) exponent

$$u(z) = u_{ref} \left(\frac{z}{z_{ref}} \right)^\alpha$$

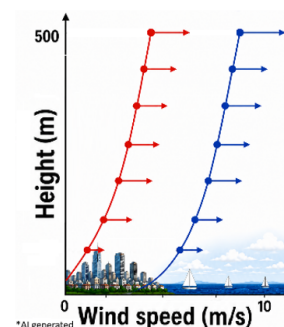


Figure 4.5. Wind profile power law.

4.3. Module 3: Physical Conditions and Wind Potential for Offshore Wind Farms in the Adriatic

Physical conditions of the four BEYOND project pilot regions, as shown in Figure 4.6, and wind potential at these sites will be analysed. Two of these regions are located along the Italian coastline and two along the Croatian coastline.

Italian side of the coast

■ Apulia region

■ Veneto region

Croatian side of the coast

■ Istria region

■ Split-Dalmatia region



Figure 4.6. Pilot regions.

The evaluation of site suitability for offshore development is based on a comprehensive analysis of several key factors. These factors can be grouped according to their type into physical and non-physical conditions, as shown in Figure 4.7.



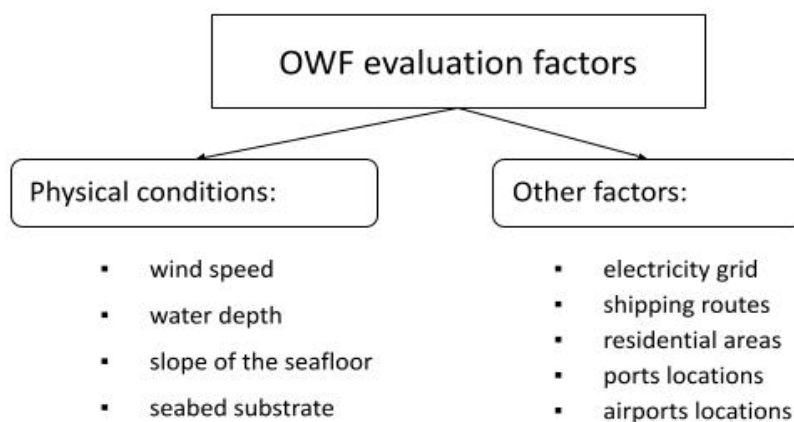


Figure 4.7. Evaluation factors.

Wind speed will be assessed as the primary parameter influencing the energy production potential and overall efficiency of the wind farm (Figure 4.8). Reliable and consistent wind conditions are essential for maximising energy output and ensuring economic viability. A set of physical conditions related to installation complexity are water depth, seabed substrate and slope of the seafloor. Together, they dominantly influence the technical feasibility, required infrastructure, and potential costs associated with the construction and connection of offshore facilities.

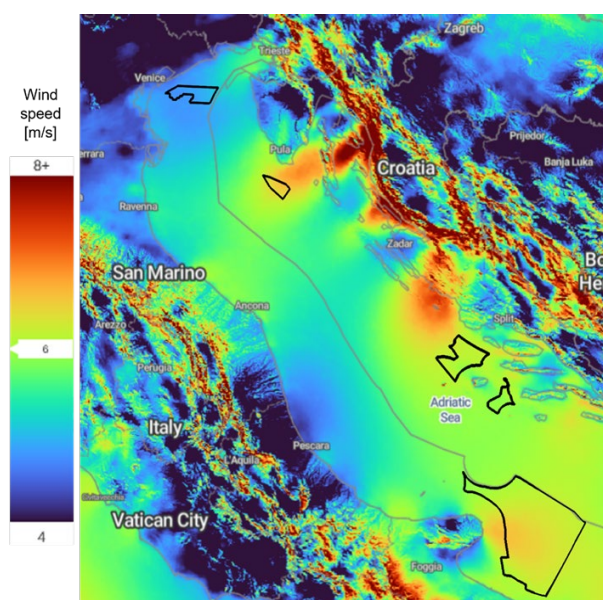


Figure 4.8. Wind speed at four pilot regions.



For the assessment of offshore wind energy potential within the selected BEYOND pilot areas in the Adriatic Sea, it is important to select a wind turbine (WT), model as turbine characteristics directly influence power production estimates. In the context of wind energy potential analysis, the turbine model defines the conversion relationship between the available wind resource and electrical energy output, thereby determining the comparability of energy yield estimates across each pilot location. In future, using next-generation wind turbines for moderate wind speeds with better rated power and larger rotor diameter will further reduce the number of units required per wind farm while significantly increasing overall energy yield. Therefore, choosing the best wind turbine type is a crucial step for estimating energy potential analysis on potential locations.

For pilot regions, a simple grid layout was proposed for the micro-siting of wind turbines. Micro-siting implies the specific positioning of each wind turbine within the potential OWF pilot region. The distance between the turbines, in a layout grid, is determined as $5D$, where D is the rotor diameter. An IEC S, Vestas V236-15.0 MW wind turbine model, with a rotor diameter of 236 m, working at wind speeds between 3 and 31 m/s, was used to present the design of the OWF with a nominal power output of 500 MW. The proposed OWF layout for the four pilot regions is shown in Figure 4.9, with annual energy production (AEP) provided in Table 4.1.

Table 4.1. Annual energy production (GWh) for 500 MW OWF configurations.

	Veneto region	Istria region	Split-Dalmatia County	Apulia region
AEP [GWh]	883	1327	1326	1471



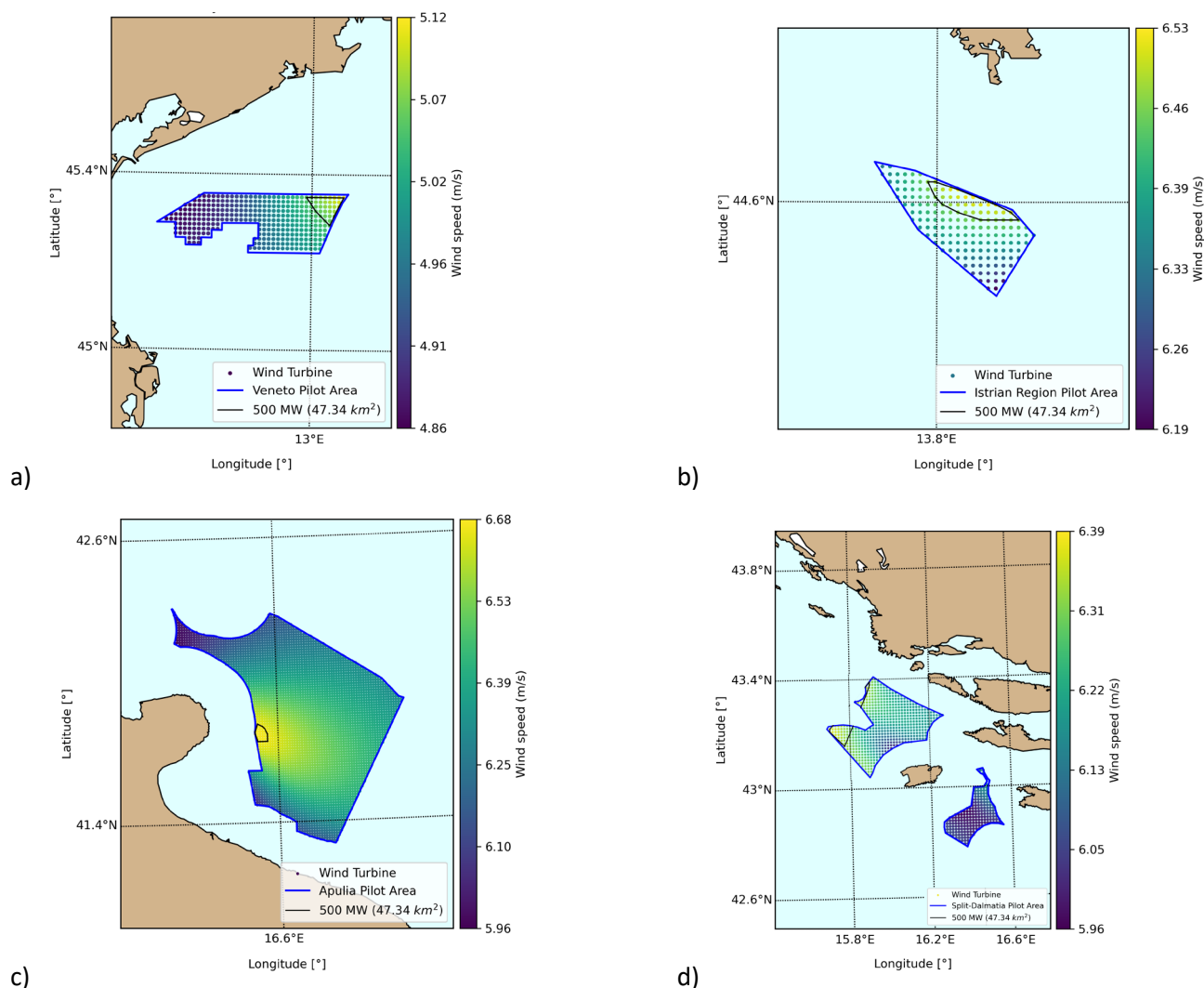


Figure 4.9. Spatial turbine layout of OWF's for 500 MW capacity: a) Veneto region, b) Istria region, c) Apulia region and d) Split-Dalmatia County region.

4.4. Module 4: Offshore Wind Farm Layout Optimization

The wind farm layout optimisation (WFLO) represents a multi-objective and multi-constraint optimisation problem, and primarily involves determining the ideal placement of turbines, planning the routing of electrical cables, and designing suitable foundations, while simultaneously satisfying a wide range of



technical, economic, environmental, and regulatory constraints. Selecting turbine locations is crucial for maximising energy production by reducing the wake effect, which causes a decrease in wind speed behind turbines and can lead to power losses of up to 10-20% of the annual energy production. Overall, WFLO aims to increase energy output while lowering the levelized cost of energy (LCOE) and maximising annual energy production (AEP), making wind farm projects more economically viable. In addition, other potential objectives may include minimising capital expenditures (CAPEX), operational expenditures (OPEX), installation time, electrical losses, structural loads, and environmental impact. Table 4.2 shows parts of the WFLO framework, with listed input data, constraints, and optimisation goals. To support advanced and cost-effective layout designs, heuristic optimisation methods such as genetic algorithms (GA) and particle swarm optimisation (PSO) are commonly applied.

Table 4.2. Factors for consideration during optimisation for OWF layout.

Input data	Constraints	Goal
• Wind speed • Sea depth • Seabed substrate type • Slope of the seafloor • Wind turbine type • Distance to the shore • Cost of wind turbine, installation, foundations, cables	• Minimum distance between WTs • Polygon boundary constraints	• Minimisation of the LCOE • Maximisation of AEP

4.5. Module 5: Wind Turbine Airfoils

Understanding wind turbine airfoils is essential because they are the fundamental aerodynamic elements that determine how efficiently a wind turbine converts wind energy into mechanical energy. The blade is composed of a series of airfoil cross-sections whose geometry changes from the root to the tip to maximise performance under varying operating conditions. A basic part of wind turbine blades and airfoils is presented in Figure 4.10. The root is the innermost part of the wind turbine blade, where it is attached to the hub. Due to the highest structural loads, it is thicker and stronger than the rest of the blade. The



tip is the end of the blade, located farthest from the hub, which moves at the highest rotational speed. The leading edge and trailing edge are the front and rear edges of the airfoil, while the straight distance between them is called the chord. Usually, to maximise energy production, the chord is not perpendicular to the wind direction. The Angle of Attack (AoA) is defined as the angle between the wing's chord line and the wind direction.

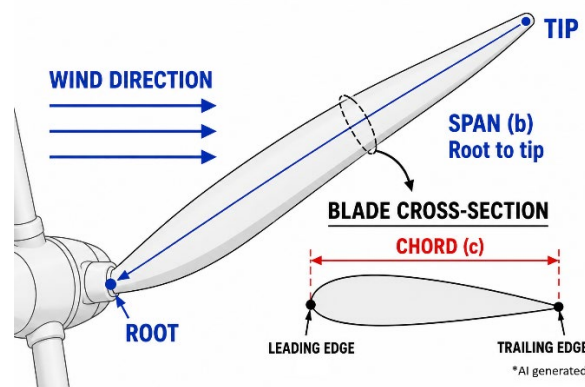
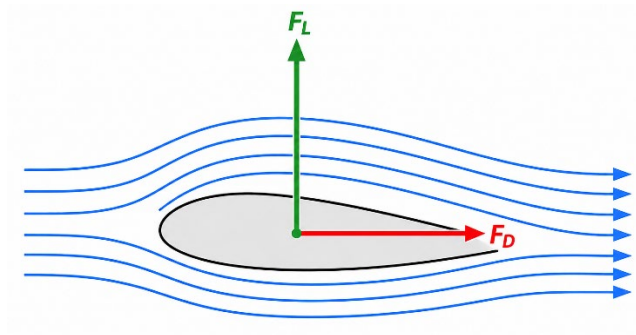


Figure 4.10. Wind turbine blade.

A wind turbine rotates because air flows around the blade, creating a pressure difference causing lift and drag forces. The lift force acts perpendicular to the direction of the air. The drag force acts parallel to the direction of the air and reduces aerodynamic efficiency, creating structural fatigue. Directions of drag and lift forces are shown in Figure 4.11. For asymmetric and angled airfoils, air flows faster over the upper side of the airfoil due to its specialised shape, compared to the bottom side. This speed difference causes a pressure difference, with low pressure on the upper side and higher pressure on the bottom side, which pushes the wing upward. By adding these two forces together, we get the total force which acts on the airfoil, commonly called the aerodynamic force. To compare different airfoils without considering their actual size or wind speed, the drag (C_D) and lift (C_L) coefficients are usually used. They are dimensionless quantities that describe the aerodynamic performance of an airfoil or blade shape, which can be calculated as shown in Figure 4.11.





$$C_L = \frac{F_L}{\frac{1}{2}\rho v^2 A} \quad C_D = \frac{F_D}{\frac{1}{2}\rho v^2 A}$$

Where:

F_L and F_D - Lift and drag force

ρ - Air density

v - Wind speed

A - Reference area

Figure 4.11. Drag and lift coefficients and forces.

To describe how the local pressure on an airfoil differs from the free-stream pressure, the pressure coefficient (C_p) is used. It is used to identify flow separation, stall and aerodynamic losses. Stall is an aerodynamic condition in which the angle of attack becomes too large, causing flow to separate from the airfoil surface, resulting in a sharp decrease in lift and a significant increase in drag forces. Hence, it is important to choose an optimal angle of attack, where the lift-to-drag ratio is highest. A higher ratio between lift and drag indicates more turning force and less energy loss, increasing the electrical power output of the turbine. Most wind turbines continuously adjust the pitch angle of the blades to have an optimal angle of attack.

4.6. Module 6: Offshore Wind Turbines Foundation Types

Offshore wind turbine foundations are almost always individually designed to suit the specific conditions of each site. The foundation design is influenced by several factors, such as the turbine type, environmental conditions, and seabed characteristics. Among these, water depth is the most decisive factor in selecting the appropriate foundation solution, thereby classifying offshore wind turbine foundations into two main categories: fixed and floating, with properties shown in Figures 4.12 and 4.13.



Fixed foundations types	GRAVITY	MONOPILE	TRIPOD
	 - relies on its own weight for stability - suitable for very shallow waters and smaller wind turbines - placed on the seabed without piling	 - 1 large steel tube driven into the seabed - most commonly used type due to its simplicity and cost-effectiveness - used in shallow waters (<40 m).	 - 3 legs and a central shaft - high stability - used in deeper waters (<50 m)
	TRIPILE	JACKET	
	 - 3 steel piles connected by a steel structure - good stability at medium depths - more complex installation requirements	 - a steel lattice structure with 3 or 4 anchoring points in the seabed; - excellent load-bearing capacity and - suitable for deep waters (<60 m) and large turbine assemblies, - challenging and costly to manufacture	

Figure 4.12. Offshore Wind Turbines Fixed Foundations

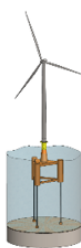
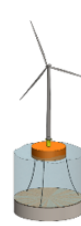
Floating foundations types	SPAR	TENSION-LEG
	 - tall, slender, cylindrical structure with a low centre of gravity → excellent stability - large dimensions → fabrication, transport, and installation challenging - suitable only for deep-water sites	 - anchored to the seabed using pre-tensioned mooring lines - high vertical stiffness and limited motion - technically complex and costly installation and maintenance process
	SEMISUBMERSIBLE	BARGE
	 - multiple buoyant columns connected by a structural frame - good hydrodynamic stability and adaptability to a wide range of sea conditions.	 - simpler, shallow-draft platform - easier and less expensive to construct - exhibits low stability in dynamic sea states - limits its applicability to calm and sheltered waters

Figure 4.13. Offshore Wind Turbines Floating Foundations



4.7. Module 7: Application of CFD for offshore wind farms

Computational fluid dynamics (CFD) is a method for solving the equations of fluid flow and simulating it using specialised computational software. Traditional experimental testing methods can be costly and time-consuming. On the other hand, specialised software (e.g., Ansys Fluent, OpenFOAM, Simcenter STAR-CCM+, etc.) solves fluid flow equations using computational methods, which can be used for analysis of the fluid flow. This approach has lower cost and better flexibility to easily investigate a wide range of flow conditions in the whole domain under full-scale operating conditions. Such models are especially important as early-stage design support and for optimisation of turbine performance, foundation placement, or wind farm layouts.

In CFD preparation, there are a few main steps which should be adhered to. In other words, there is a general procedure in CFD simulations which includes the following steps:

- 1) Geometry preparation,
- 2) Numerical grid construction,
- 3) Numerical simulation setup,
- 4) Results analysis.

First of all, it is required to have a computational geometry, either two dimensional (2D) or three dimensional (3D). In this case, the term computational geometry refers to the geometry which represents the fluid which is intended to be simulated. In addition, all solid elements need to be removed from that domain. Specifically for the wind turbine blade cross-section, the fluid domain for the CFD is all around, while in the place of the solid element (the place of the airfoil) there should be emptiness (Figure 4.14).



Figure 4.14. Fluid domain geometry.



After the geometry is created, the next step in CFD preparation is the construction of the numerical grid (mesh) for the created fluid domain. The role of the numerical grid is the division of the created domain into smaller parts commonly called cells (Figure 4.15). In this way, fluid flow equations are solved at each cell centre. This enables obtaining simulation results at a large number of spatial points, which leads to obtaining the overall picture of the fluid flow. During the numerical simulation, cells communicate and exchange information. Overall numerical grid quality has a direct influence on the simulation results. In addition, a more complex numerical grid, or in other words, numerical grids with more cells, leads to higher computational complexity of the CFD simulation. Again, it is important to make a balance between the accuracy of numerical results and computational time.

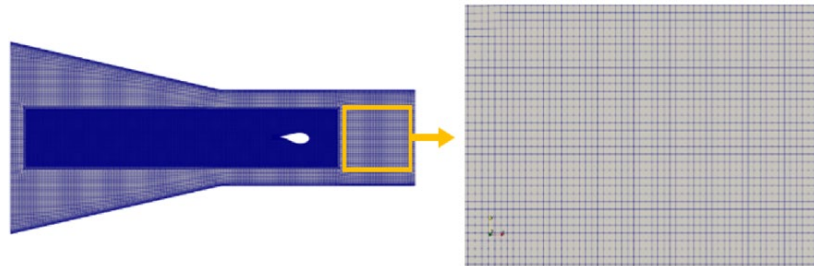


Figure 4.15. Example of a numerical grid

Fluid velocity at the walls is equal to zero (no-slip condition), while moving away from the wall, the fluid velocity increases rapidly. Therefore, very intense fluctuations in the fluid flow are present in the relatively narrow zone around the wall. To obtain accurate CFD simulation results, it is necessary to capture and simulate all these changes in an appropriate way. For that purpose, boundary layers are used in CFD simulations. In general, boundary layers are a relatively narrow strip of the numerical grid around the no-slip walls. The numerical grid in these places is constructed from smaller parts compared to the rest of the domain. Furthermore, layers of the numerical grid grow from the smallest cell size at the wall boundary, moving away to the outer zones, until reaching the global numerical grid size.

The last step, before results analysis, is the simulation setup. In that step, it is necessary to implement the physics of the analyzed case into the software and computational language in an appropriate way.



Roughly, that includes defining the states at the domain boundaries (boundary conditions), fluid characteristics, flow model (laminar, turbulent, mixture, etc.), influence of gravity if it exists, simulation type (steady state or transient), solver type and methods, etc.

Once each of the conducted numerical simulations converged, it is possible to analyse and compare the obtained results. This usually includes pressure differences, velocity magnitudes, forces including drag and lift and dimensional coefficients, which enable comparison of fluid flow for different conditions. Although there are many benefits of the CFD model, it is also important to compare results and validate with laboratory experiments to provide confidence in the numerical models. Since CFD simulation relies on assumptions, numerical methods, and simplified physical models, validation demonstrates whether the simulation accurately represents the real physical behaviour. It also helps to determine if the chosen mesh, boundary conditions, turbulence model, or numerical approach is appropriate for the problem. For an offshore wind farm, comparison of model results with field measurements from operating wind farms provides the final validation under real atmospheric and marine conditions.

4.8. Module 8: The Need for Green Energy Production and the Potential of Marine Renewable Energy

The global energy sector is undergoing a profound transformation driven by the need to reduce greenhouse gas emissions, improve energy security, and meet the rapidly growing demand for electricity. Renewable energy sources are becoming central to this transition, requiring not only technological innovation but also the development of new energy infrastructures and sustainable planning approaches. This module provides an overview of the energy transition process with a particular focus on the opportunities and challenges faced by coastal regions. Using examples from the Adriatic Sea and the Region of Istria (Croatia), the presentation examines the role that marine renewable energy technologies may play in supporting future energy systems. Particular attention is given to offshore wind energy, seawater-source heat pumps, floating photovoltaic systems, and other



innovative solutions that can contribute to decarbonisation while respecting environmental and spatial constraints.

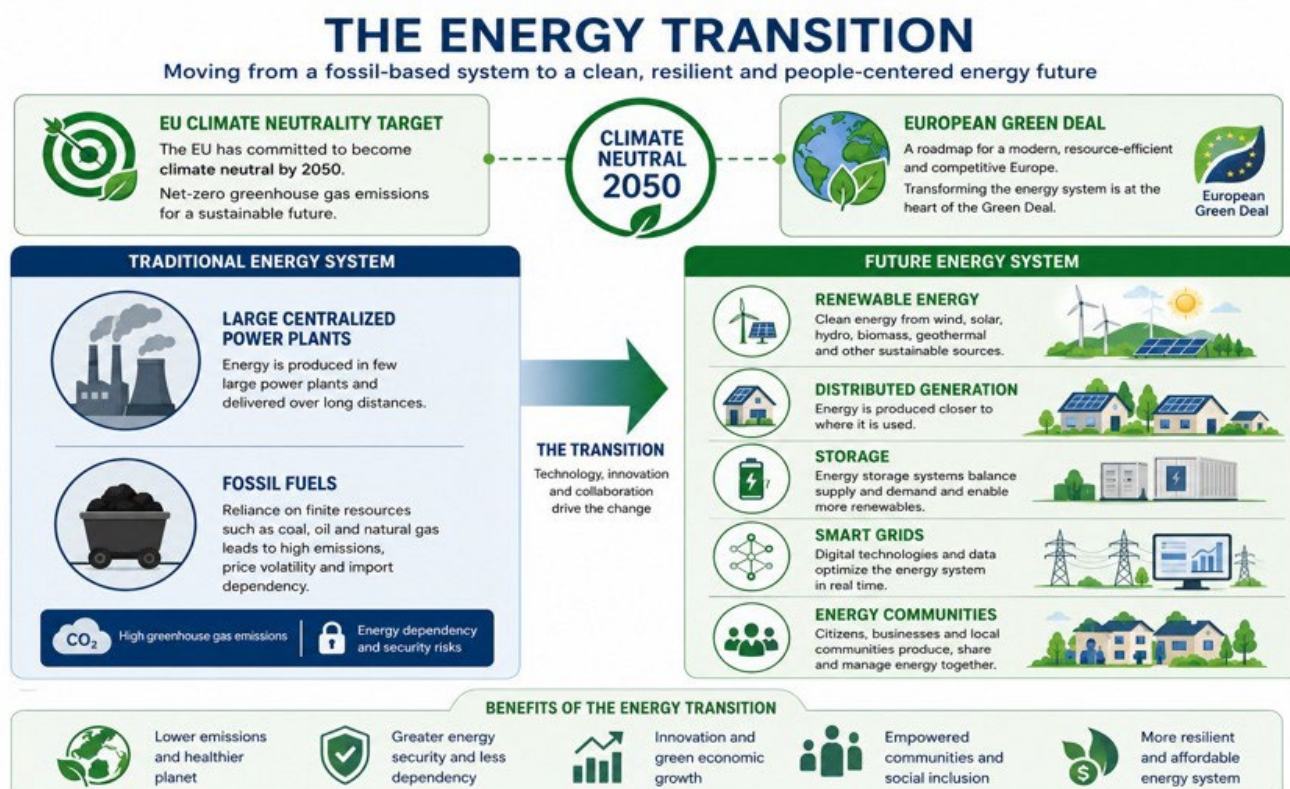


Figure 4.16. The Energy Transition

The introductory module of the environmental pillar of the syllabus will, therefore, provide students with an overview of the context, focusing on regional energy challenges, including increasing electricity demand, grid limitations, the gradual phase-out of fossil fuel-based generation, and the need to strengthen local renewable energy production. Results and experiences from several European projects focused on marine renewable energy will be presented, highlighting both the technical potential and the practical barriers associated with the deployment of such technologies in the Adriatic region. Special emphasis will also be placed on the use of seawater thermal energy for heating and cooling applications, particularly in protected historic buildings and coastal urban areas where conventional renewable energy solutions may be difficult to implement. The module also addresses the importance



of stakeholder engagement, education, and capacity building, showcasing initiatives aimed at involving young people and future professionals in the energy transition process.



Figure 4.17. Model of an inclusive OWF

4.9. Module 9: OWF and Interactions with the Fisheries Sector

The lecture addressed the interaction between offshore wind farm development and the fisheries sector, with particular emphasis on the main operational, ecological, and governance challenges associated with the coexistence of these two marine uses. It outlines how spatial competition in the marine environment is intensifying as offshore wind expands alongside other activities and protected areas, and it highlighted the specific vulnerability of fisheries, which rely on access rights to marine space rather than ownership. The module will explore several aspects of the fisheries sector, including the distinction between fixed-bottom and floating offshore wind technologies, and how bathymetry and project design determine the nature and extent of interactions with fishing activities. The impacts of exclusion zones, cable infrastructure, seabed alteration, construction disturbance, and navigation constraints will also be examined, with particular attention given to the Mediterranean and Italian



context, with reference to the Adriatic Sea and to recent assessments of the potential effects of offshore wind development on trawlable fishing grounds, employment, and local fleets.

The material will encourage students to discuss possible pathways toward coexistence, including multi-use solutions, limited compatibility with certain static gears, data collection and monitoring roles, and nature-inclusive design. Key governance measures, such as early stakeholder engagement, cumulative impact assessment, buffer zones, compensation mechanisms, and adaptive management, will also be highlighted.

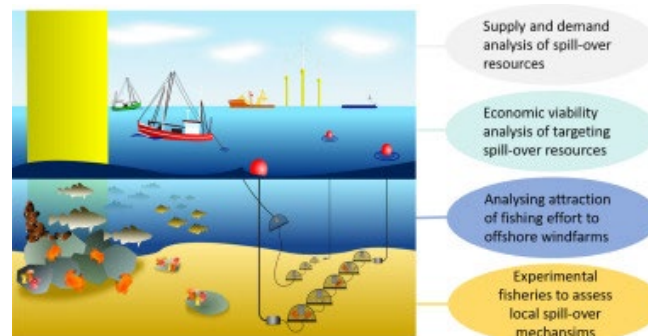


Figure 4.18. Stelzenmuller, V., Gimpel, A., Haslob, H., Letschert, J., Berkenhagen, J., Bruning, S. (2021)

‘Sustainable co-location solutions for offshore wind farms and fisheries need to account for socio-ecological trade-offs’, Science of the Total Environment,

<https://doi.org/10.1016/j.scitotenv.2021.145918>

The module will then delve deeper into the assessment of the potential direct and indirect impact of OWF development on fisheries and aquaculture, which is inherently complex and context-dependent. In particular, other than direct assessment of overlap between fishing grounds and OWF, a more quantitative analysis requires quantification of catches in the planned OWF areas. Moreover, if areas dedicated to OWF are in critical habitats for commercial fish species this might result in a long term indirect impact. An integrated framework is therefore proposed by combining *four complementary levels of analysis* to evaluate these interactions:



1. the importance of determining Essential Fish Habitat (EFH) for key commercial species (e.g. in the Adriatic Sea European hake, red mullet, anchovy, sardine, rose and giant red shrimp) and assess their overlap with planned OWF areas; the determination of EFH is done using specific tools (Species Distribution Models, SDMs) that exploit monitoring data (fishery-independent surveys) and environmental data;
2. The direct overlap between fisheries and OWF is done by mapping fishing effort by gear type using Vessel monitoring system (VMS) and/or Automatic Identification System (AIS) that are used to track the fishing vessels and can be used to quantify current spatial overlap;
3. As a potential direct impact, the module proposes to quantify the quantities of catches actually collected in OWF planned areas using information on fishing grounds and species distribution. The estimated spatial catches represent information connected on jobs and value that are dependent from areas that in the future are dedicated to OWF. Even if this is not necessarily the impact on the sector, because it depends largely on management of OWF, it represents a useful quantification for planners and for discussion with stakeholders;
4. The last element of the module is the analysis of marine concessions between planned OWF sites and existing aquaculture areas. Again, this is not at all a measure of impacts of OWF but this quantification highlights possible conflicting sites as well as sites where adaptation measures can be adopted.

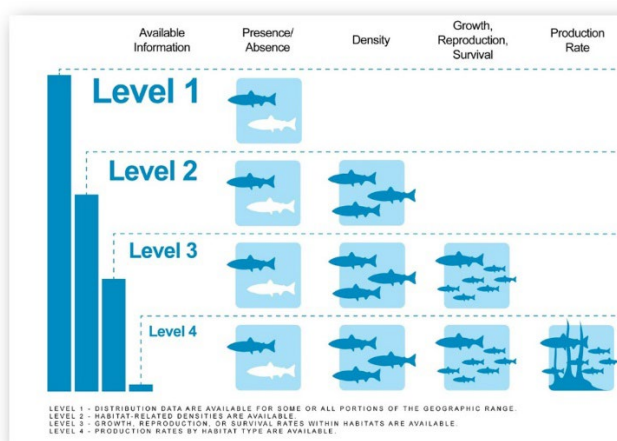


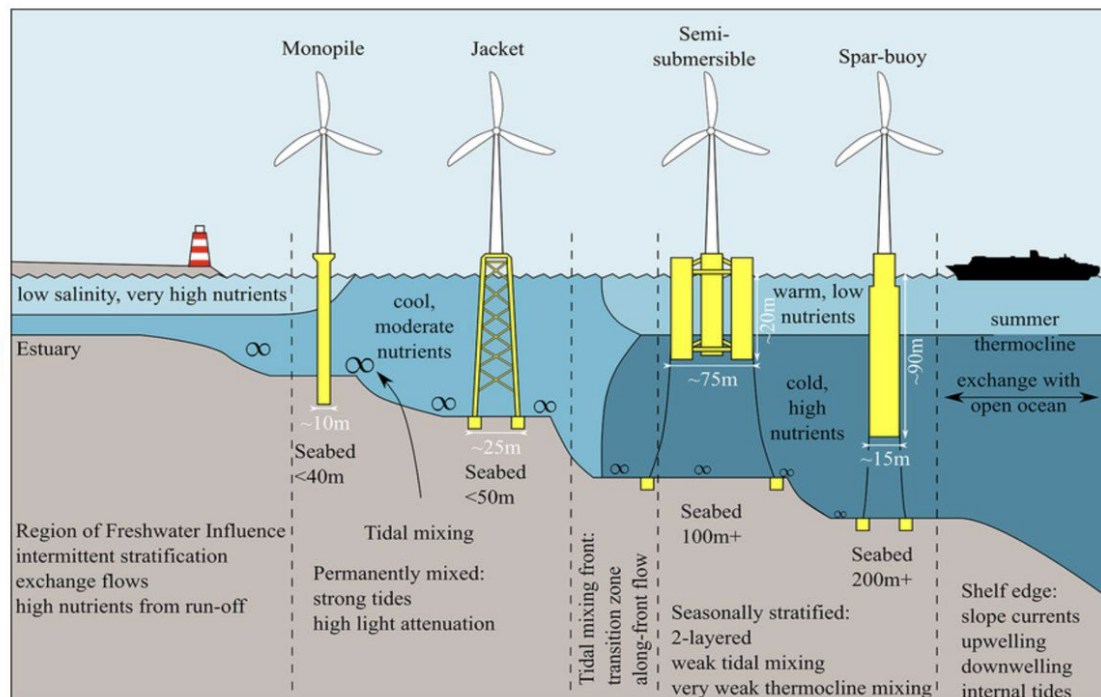
Figure 4.19. Essential Fish Habitats (EFHs)

4.10. Module 10: Geohazards and OWFs

Within this module, students will be introduced to the identification and characterization of geohazards that require an integrated, multi-scale approach combining high-resolution multibeam bathymetry and backscatter, seismic reflection profiling, geological and geotechnical investigations, and direct observations using ROVs and AUVs. Real-life examples will be used for example, from the Calabrian margin in Italy, to illustrate how submarine canyons, landslides, active faults and fluid-related features can be mapped and investigated, and how repeated observations can help constrain active processes and identify areas requiring long-term monitoring.

Students will learn how marine geohazards do not automatically translate into risk. Risk depends on the interaction between the hazard itself, the vulnerability of offshore infrastructure and its exposure. Consequently, the relevance of individual geohazards varies according to geological setting, water depth, offshore wind technology and project configuration. Students will therefore, understand how reducing uncertainty through appropriately designed site investigations and monitoring is essential for risk-informed decision making throughout the entire offshore wind farm lifecycle. Finally, the module will discuss the role of Marine Spatial Planning as a framework for integrating geological safety with wind resources, technological constraints, environmental protection and competing uses of marine space. In geologically active regions such as the Mediterranean, marine geohazards cannot always be avoided, but their identification, characterization and monitoring can substantially reduce uncertainty and support safer and more sustainable offshore wind development.





Existing and emerging offshore wind engineering solutions (Díaz and Soares, 2020; Jiang, 2021b), including fixed monopile and jacket foundations and floating semi-submersible and spar-buoy foundations, in comparison to shelf sea regimes from coastline to open ocean (Simpson and Sharples, 2012).

Figure 4.20

4.11. Module 11: Ecological-Acoustic Impacts of Infrastructures at Sea

Any type of infrastructure can alter marine ecosystems by causing negative impacts during construction activities (e.g. direct physical alteration, sediment resuspension or noise pollution) and after construction, leading to habitat fragmentation, pollution risk and the introduction of invasive species, thus resulting in biodiversity loss and consequently loss of ecosystem services. However, the presence of infrastructures may also have long-term positive effects on the environment, as they can act as artificial reefs, favour the settlement of hard-bottom communities and/or lead to the institution of restricted areas for other activities that could be harmful to the environment (e.g. trawling fisheries), thereby allowing the habitat to recover. Marine infrastructures can also contribute to the creation of new habitats and increase benthic spatial complexity by creating three-dimensional complex structures on typically homogeneous sedimentary bottoms. This module aims to explore all of these effects that may



or may not promote a gain in local biodiversity. Whatever the impact on marine ecosystems, the installation and management of infrastructures must be efficiently monitored with the aim of minimising or mitigating potential harm to marine biota. The material will also touch upon European Union legislation, including the Water Framework Directive and the Marine Strategy Framework Directive, which both aim to assess the ecological and environmental status of water bodies through the study of Biological Quality Elements (BQEs). Data collection is also explored within the module through M-AMBI, which is now the official index for macroinvertebrates used to determine the ecological status of water bodies, with results expressed as an EQR (Ecological Quality Ratio), and how to interpret them.

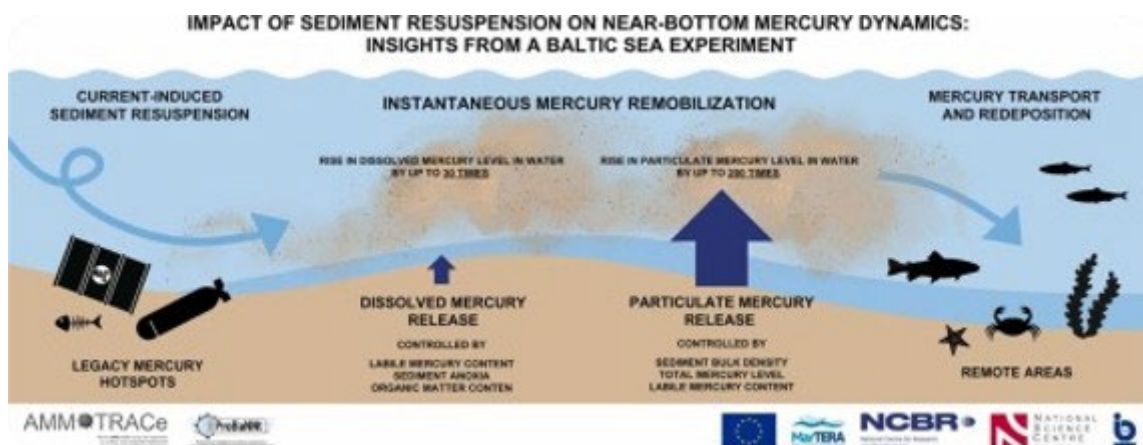


Figure 4.21. Impact of sediment resuspension on near-bottom mercury dynamics

The module also introduces the ecological importance of underwater sound and the potential vulnerability of marine mammals to anthropogenic noise. It will then allow students to examine the different phases of the OWF life cycle—site investigation, construction, operation, and decommissioning—highlighting the distinct acoustic sources associated with each stage and their potential impacts. Key considerations for monitoring underwater acoustic environments are also presented, including the design of monitoring programs and the role of Passive Acoustic Monitoring as a non-invasive tool for detecting marine mammals and assessing changes in soundscapes. Current



knowledge on the behavioural and physiological effects of underwater noise on marine fauna is reviewed, together with the challenges of distinguishing short-term responses from long-term ecological consequences. Finally, the module will present commonly adopted mitigation measures aimed at reducing acoustic impacts, such as temporal planning, exclusion zones, noise attenuation technologies, and adaptive monitoring strategies.

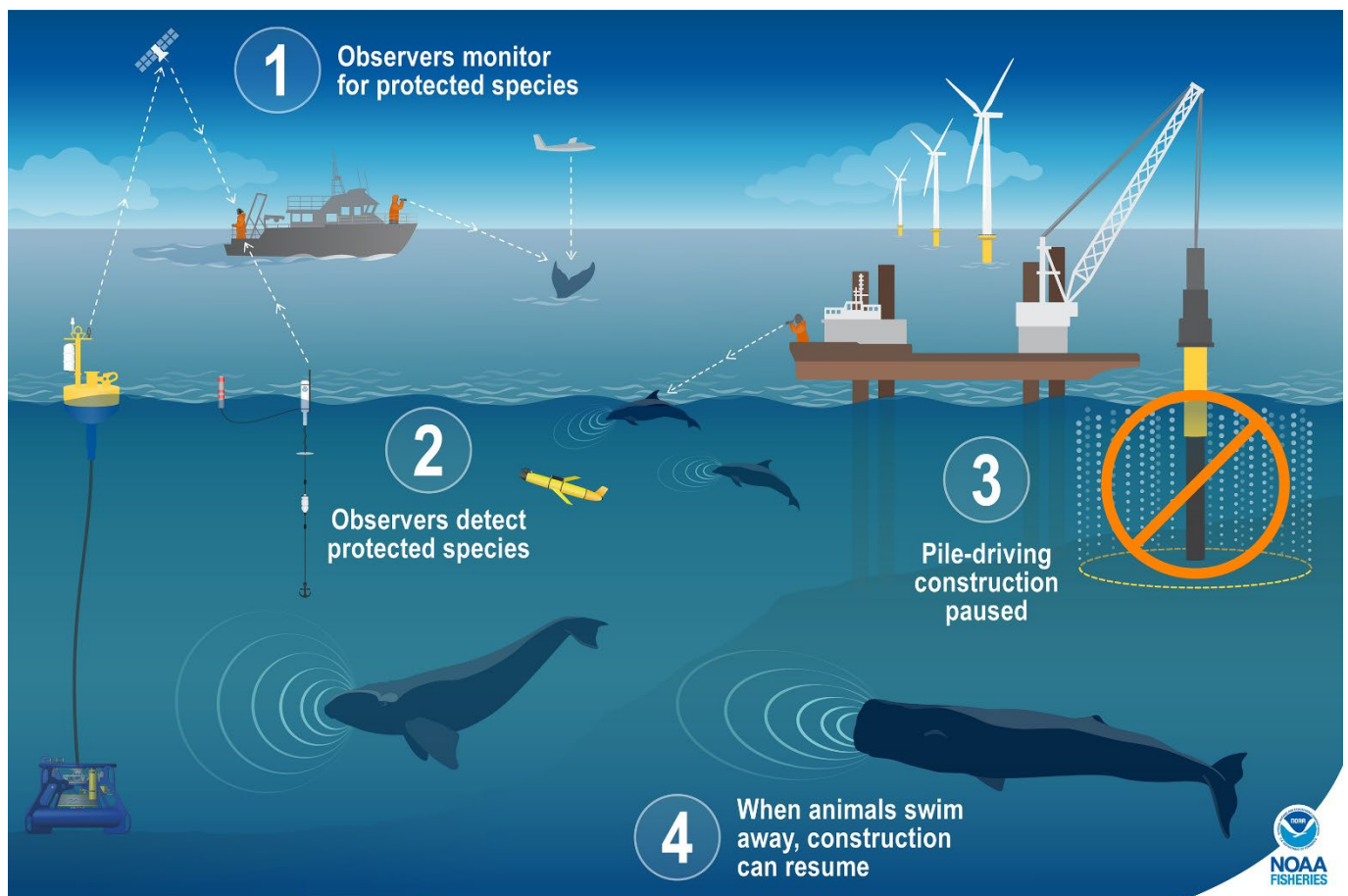


Figure 4.22. NOAA recommendations for use of passive acoustic listening systems (5 June 2025), <https://www.fisheries.noaa.gov/new-england-mid-atlantic/offshore-wind-energy/noaa-recommendations-use-passive-acoustic-listening-systems>



4.12. Module 12: The Role of MSP for the Sustainable Development of Offshore Wind Farms

The need for Marine Spatial Planning (MSP) has increased worldwide due to the rapid expansion of human activities at sea (Jouffray et al., 2020) for the so-called the blue acceleration, i.e., the trajectory of human expansion into the ocean. As a consequence, there is an increase in cumulative impacts across the entire global ocean (Halpern et al., 2008). MSP development has been particularly rapid in the European Union driven by the EU MSP Directive (2014/89/EU) and currently, 20 out of 22 EU coastal states have adopted MSP plans. In this context, the module will explore the core function of MSP in order to manage conflicts and promote synergies between marine uses, including offshore renewable energy (ORE). The occurring and expected expansion of ORE, offshore wind energy (OWE) in particular, can create spatial conflicts with traditional sectors like fisheries. These might result in the subtraction of fishing grounds, altered routing, and possible increase in fuel cost impacts. Students will be invited to reflect on how MSP can help address these conflicts by avoiding main fishing grounds, allowing co-location of certain typologies of fisheries, and enabling navigation through OWFs. Conflicts with tourism are mainly related to the visual impacts of OWE near coastal areas, requiring careful site selection, e.g. beyond the 12 nautical miles whenever doable. Students will also consider how MSP can help manage conflicts with shipping as well, avoiding overlaps between OWE and main traffic lanes and advocating for rerouting when necessary.

The module will also address the several challenges facing ORE integration into Mediterranean MSP, such as (i) the rapid scaling of floating wind farms, (ii) the creation of hybrid offshore energy systems combining wind, floating solar, and wave technologies, (iii) the combination of offshore wind energy with the production of clean fuels (hydrogen, methanol, etc.), and (iv) the development of large offshore energy hubs including combination with other uses (multi-use). Given that several ORE-related considerations extend beyond national borders, e.g. ORE environmental impacts, regional production targets, grid infrastructures, and more, transboundary cooperation in MSP is therefore vital. The module



will introduce the topic of these cross-border challenges and highlight how they are a core focus of the Mediterranean Community of Practice on Maritime Spatial Planning (MED-MSP-CoP). Finally, the module will explore a small number of local case studies to highlight MSP in action.



Figure 4.23. Release of infographic on maritime spatial planning in the EU (7 December 2022),

<https://maritime-spatial-planning.ec.europa.eu/news/release-infographic-maritime-spatial-planning-eu>



4.13. Module 13: Planning an Offshore Windfarm, Compensation Activities and Valorisation

This module will explore the real-life large-scale 330 MW offshore wind farm “Rimini” (Energia Wind 2020) as a case study providing valuable insights into the project and its strengths, main works on sea and land, and the design of the layout, which was based on three criteria:

- Landscape and environmental protection considerations;
- Rational use of Marine Space and interactions with other uses;
- Technical and wind resource considerations aimed at optimizing energy production.

The offshore wind farm “Rimini” has been designed with a focus on coexistence with current marine uses and, above all, with new environmentally sustainable activities. The module will also enable students to explore the concept of Nature Inclusive Design (NID), and how the goal of the structure has been to create an accessible space — a place where the following proposed enhancement actions can be implemented, integrated, and synergistic with energy production:

- Regeneration of marine habitats and seabeds;
- Ecotourism and sustainable tourism;
- Recreational and sports activities;
- Sustainable fishing and aquaculture;
- Energy efficiency.



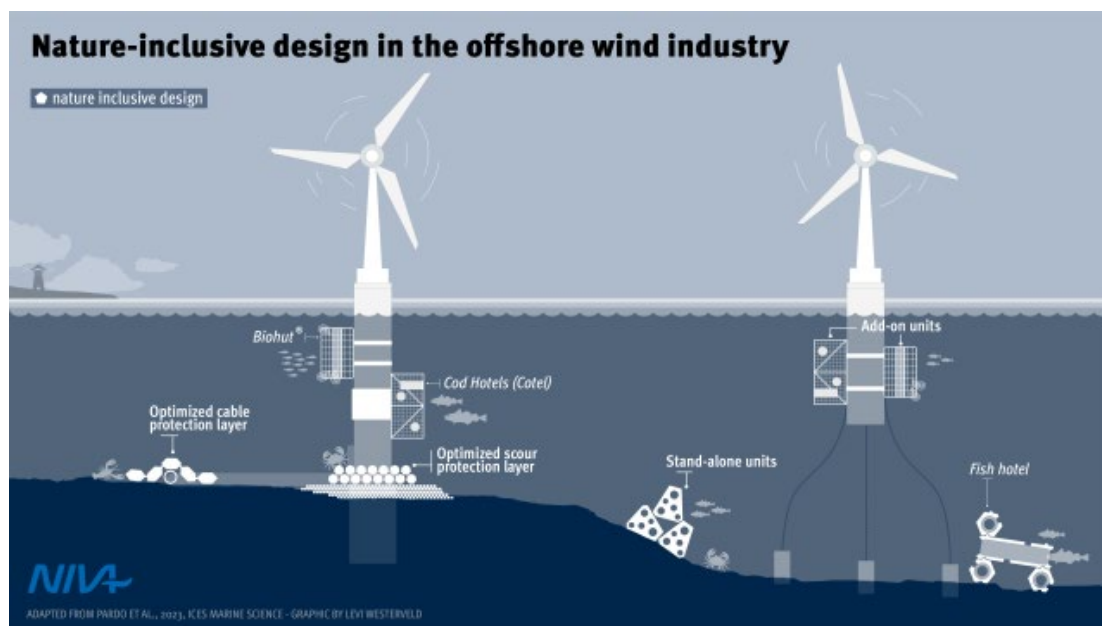


Figure 4.24. An illustration from the NiD4Ocean project with examples of nature-inclusive design in the offshore wind industry. Adapted from Pardo et al, 2023. ICES Marine Science. Graphic by Levi Westerveld. All rights reserved: NIVA

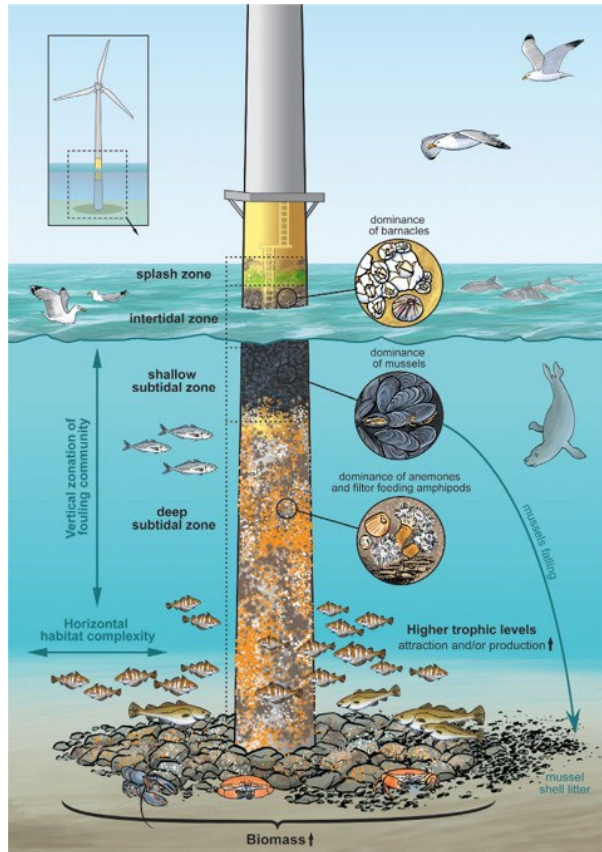
Moreover, the OWF can be developed as an Environmental Monitoring Platform open to local environmental associations and organizations and public research institutions for different measurements and research activities that need to be conducted at sea. The offshore wind farm could provide important information on the behaviour and presence of birds and fish, marine climate and weather characteristics, wave motion, water and seabed quality, sediments, underwater noise and microorganisms.

4.14. Module 14: Ecosystem Approach for Analysis of Cumulative Impacts of Offshore Wind Farms

Offshore wind farms can have both positive and negative impacts on marine ecosystems. Studies reported in this module show the impacts that OWF can have:



Figure 4.25. Degraer et al., *Oceanography*, 2020



- on local circulation and plankton communities;
- on local benthic communities for the creation of new hard substrate to colonize;
- as aggregating devices, thus influencing fish aggregation; can act as barriers displacing species or hampering their migrations;
- add new layers of disturbances creating underwater noise, resuspensions or habitat modifications;
- the modification of fishing activities induced by OWF can also affect fish communities.

Overall, these effects acts synergistically or in antagonism to create a set of cumulative effects on the food webs. Such effects are not necessarily linear, plus they are not necessarily additive and finally have a series of indirect cascading effects. Therefore, tools that

enable to quantitative represent these effects are needed to obtain demonstration of effects and facilitate ecological optimization of OWF placement.

Evaluating the impacts of OWFs on marine environments often relies on single-aspect models. While these tools offer high local detail, they generally overlook complex ecological interactions. To address this limitation, spatial ecosystem models provide a holistic approach to evaluating the ecosystem-wide and socio-economic consequences of OWF developments. This module will present a case-study framework using a spatial Ecospace model (www.ecopath.org) of the Adriatic Sea to simulate OWF integration and assess trade-offs between renewable energy targets, ecological conservation, and fisheries management. The model represents a simplified food web comprising 40 ecological groups and 18 fishing fleets. Different management scenarios will be explored, enabling students to interactively



work in groups to quantify the impacts with the goal of identifying optimal spatial setups that balance renewable energy goals while minimizing ecological degradation and socio-economic drawbacks for local fisheries.

4. Conclusion

In conclusion, the syllabus of this unique cross-border program on OWF has been designed in a way that allows for adaptation and further refinement in the future as the field continues to develop, while remaining loyal to the core technical and environmental learning materials it is built on. Keeping in mind the aim of producing a multimodal syllabus that provides students with differing backgrounds the opportunity to develop their knowledge in the field, it is foreseen that this learning program will act as the reference point for future capacity building with respect to OWF and its effects, with the order and progression of each module having been designed to help students identify how each area is interconnected. Combining both technical and environmental aspects fosters a more global and holistic understanding of the impacts of OWFs, helping teachers and students alike improve their understanding of how OWF energy can be harnessed in an economically viable way that guarantees environmental sustainability for the present and the future.

