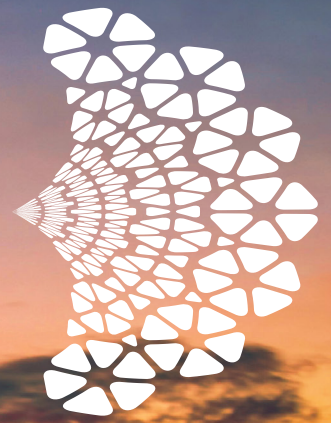


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Engaging Offshore Wind Sector in Marine Spatial Planning

Volume 1 - Sector overview



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**United Nations
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Engaging Offshore Wind Sector in Marine Spatial Planning

Volume 1 - Sector overview

IOC Technical Series No. 197, Volume 1

UNESCO 2025

Executive Summary

Introduction

As offshore wind energy expands globally, marine spatial planning (MSP) plays a crucial role in ensuring its sustainable integration within the marine space. In the context of the MSPglobal Programme, this publication targets MSP practitioners and offshore wind (OW) experts with the ultimate goal to provide practical recommendations for integrating OW into MSP processes, outlining key phases and good practices. It consists of two volumes, with Volume 1 presenting an overview of the sector, focusing on its spatial characteristics, lifecycle, and interactions with marine activities, and the second presenting an overview of MSP, its phases and relevant good practices to engage OW stakeholders in the MSP process based on global experiences.

Basic Concepts

Offshore wind has evolved from the early land-based windmills to large-scale OW farms, driven by the global need for energy security and carbon reduction. Today, the sector is expanding rapidly, with leading markets in China, the United Kingdom, Germany, and Denmark, and emerging markets mainly in Southeast Asia, the Middle East, and North America. As offshore wind capacity grows, planners must anticipate increasing spatial pressures and conflicts with other marine activities.

Lifecycle of the OW sector

The offshore wind sector follows a structured lifecycle, with each phase presenting different spatial challenges:

- **Planning and scoping:** Identifying potential sites, balancing energy potential with environmental and sectoral constraints.
- **Development and siting:** Conducting feasibility assessments, stakeholder engagement, and impact evaluations.
- **Pre-construction:** Finalizing designs and infrastructure planning, securing financial and regulatory approvals.
- **Construction:** Installing turbines, foundations, and grid connections, requiring marine space coordination.
- **Operation and maintenance:** Ensuring long-term efficiency, integrating monitoring and environmental safeguards.
- **Decommissioning or repowering:** Removing or upgrading infrastructure, addressing site restoration.
- **Disposal and reuse:** Managing end-of-life turbine components.

Regulatory and legal frameworks

International frameworks, such as the United Nations Framework Convention on Climate Change (UNFCCC), have driven offshore wind expansion, influencing national policies and climate targets. MSP practitioners need to navigate different regulatory models, such as the **plan-led approach**, where governments designate OW development zones within MSP or other planning frameworks, and the **developer-led approach** which adopts a market-driven site selection, requiring spatial coordination to balance industry needs with conservation and marine activities.

Another differentiation exists between **centralized** and **decentralized governance** systems, referring to decision making processes for planning, permitting and policy implementation. Countries are increasingly adopting the 'one-stop-shop' permitting processes to help streamline approvals, optimizing time and reinforcing the need for MSP coordination to integrate offshore wind efficiently.

The rise of the offshore wind sector is raising concerns regarding skills and expertise needed throughout the cycle, with senior management and environmental expertise needed in early development phases. This gap could be filled by engaging MSP experts with expertise in offshore spatial management.

Technical and spatial considerations of offshore wind

OW farms require the use of marine and coastal spaces, necessitating careful planning to avoid conflicts with existing uses and to ensure resource optimization.

- **Infrastructure** considerations include turbines and their foundations, subsea cables, offshore substations, and onshore grid connections. There are two main types of turbine foundations: fixed-bottom, which are suitable for shallow waters (up to 60 m), and floating, which enable development in deeper waters.
- **Site selection** for OW must account for wind speeds, water depths, distance to shore, seabed characteristics and oceanographic conditions (including natural hazards). Key exclusion zones include navigation routes, marine protected areas (MPAs), military zones, key fishing grounds in addition to ecologically and culturally sensitive areas.
- **Co-existence strategies** such as multi-use planning can help integrate offshore wind with other maritime sectors such as aquaculture, hydrogen production, tourism and marine conservation.

Overall, the demand for ocean space by the offshore wind sector is expected to grow eightfold by 2050. Spatial pressures will intensify, particularly in shallow waters, resulting in potential conflicts with existing and planned maritime activities.

Impacts of the offshore wind sector

Assessing offshore wind's environmental and socio-economic impacts is essential for MSP and can be achieved by combining several tools, such as the following:

- **Sensitivity mapping** (early-stage) used to have a holistic visualization of environmentally and socially sensitive areas. It helps inform strategic environmental assessments (SEA) and OW planning processes.
- **Strategic environmental assessment (SEA)** (policy level) helps identify significant risks for offshore wind planning and development at a broader scale before projects approval. It helps streamline environmental impact assessment (EIA) processes.

- **Environmental impact assessment (EIA)** (project level) helps evaluate and mitigate site-specific effects of project proposals. It is a pre-requisite for many OW development permitting processes and a condition to achieve project consent.

Offshore wind impacts may occur throughout its lifecycle, with **construction** posing the highest environmental pressures from manufacture, installation and transport activities. **Operation** presents long-term socio-economic opportunities such as infrastructure development, job creation and energy security. Social concerns are often raised early in the process to address human rights issues during material extraction and processing, impacts on Indigenous Peoples and local communities (IPLCs) living by the coast, including disruption of their cultural practices. MSP's role is to integrate these assessments to minimize risks and optimize benefits.

Interactions with maritime sectors

Spatial planning for offshore wind development requires a comprehensive approach that accounts for the full project lifecycle. Coastal and marine infrastructure needs to be integrated into planning to ensure efficient connectivity, logistics and maintenance. Given the three-dimensional nature of the ocean, spatial considerations extend beyond the seabed to encompass the water column and airspace. Interactions occur with maritime navigation, fisheries, aquaculture, military operations, energy production, and ecological systems.

Seabed use for foundations and cabling must be carefully assessed to avoid conflicts with existing infrastructure, habitats, and archaeological sites, while exclusion zones and navigational corridors should be strategically defined to balance safety, accessibility, and co-existence with other maritime activities. Multi-use planning approaches, such as co-location with aquaculture, tourism, and hydrogen production, can help optimize spatial efficiency while minimizing sectoral conflicts.

By understanding and carefully addressing vertical and horizontal spatial dynamics, marine spatial planners can facilitate the sustainable integration of offshore wind within the broader seascape.

Activity	Conflicts and challenges with OW	Opportunities and co-existence with OW
Maritime transport	Increased route lengths, higher traffic density, collision risks, and radar interference.	Port infrastructure could benefit from OW investments, improving logistics and economic activity.
Aviation and military defence	Disruptions to radar, telecommunications, and aviation routes; security concerns may restrict OW development.	Mitigation through airspace restrictions, radar integration, and OW farms supporting security and safety operations.
Fisheries and aquaculture	Fishing displacement, exclusion zones, habitat disturbances, and aquaculture infrastructure challenges.	Artificial reefs effect potentially enhancing biodiversity; co-located aquaculture projects integrating OW farms.
Tourism and recreation	Visual impact affecting coastal tourism, recreation, and hospitality businesses.	Eco-tourism, guided tours, and recreational activities integrated into OW farms.
Conservation	Potential impacts on MPAs effectiveness as well as loss of habitat and species.	Nature inclusive design reducing impacts; OW structures enhancing marine ecosystems' structure and functioning.
Maritime and underwater cultural heritage	Risk of damage to submerged archaeological sites; restrictions on research access due to OW farms exclusion zones.	OW farms creating protected zones, limiting destructive activities; archaeological assessments improving heritage management.
Other offshore energy sectors	Spatial overlaps with oil and gas operations, carbon storage sites, offshore mining, and competition with other offshore renewables.	OW farms supporting offshore green hydrogen production, platform electrification, infrastructure sharing, and optimized geological research.

Source: Elaborated by author

Foreword

The clean energy transition is essential to meet the targets set by the Paris Agreement, which aims to limit global warming to well below 2°C, preferably 1.5°C above pre-industrial levels. Ocean-based solutions are rapidly expanding, and offshore wind is becoming a key stakeholder for Marine Spatial Planning (MSP).

The Intergovernmental Oceanographic Commission (IOC) of UNESCO has been a leading UN agency to develop international guidelines and strengthen the capacities of MSP practitioners from around the world. The UN Global Compact is the world's largest corporate sustainability initiative and is focused on accelerating and scaling the global collective impact of business through accountable companies and ecosystems that enable change.

Both organizations started working together on Marine Spatial Planning and Offshore Wind in 2021, when the UN Global Compact led the co-development of the *'Roadmap to Integrate Clean Offshore Renewable Energy into Climate-smart Marine Spatial Planning'*. This roadmap supports a more rapid, socially acceptable and just implementation of offshore renewable energy in the context of Marine Spatial Planning.

As a follow-on from the 2021 report, IOC and the UN Global Compact partnered once again on the publication you are now reading. This work is a call to action for MSP and Offshore Wind practitioners to foster meaningful engagement and support for MSP processes. It charts the MSP path towards a sustainable ocean economy.

At the core of Volumes 1 and 2 is the challenge of disseminating the multi-sectoral paradigm of MSP to all ocean users. Further highlighted is the need for MSP practitioners to become more familiar with sectoral spatial characteristics, demands and sustainable practices to mitigate the impacts on socio-ecological systems.

While Volume 1 serves as a guide to navigate through Offshore Wind concepts, status, practices and interactions with other maritime sectors, Volume 2 focuses on the key challenges and good practices to improve the engagement of the offshore wind sector in MSP. Both documents were based on desk review as well as consultations with MSP and Offshore Wind experts.



A handwritten signature in blue ink that reads 'Vidar Helgesen'.

Vidar Helgesen

Executive Secretary of IOC



A handwritten signature in blue ink that reads 'Sanda Ojiambo'.

Sanda Ojiambo

Assistant Secretary-General
and Executive Director of
UN Global Compact

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The two volumes reflect the collective effort undertaken within the offshore wind and MSP communities, and will hopefully support a smooth transition to offshore renewable energy via sustainable MSP practices.



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1. UNESCO-IOC: <https://www.ioc.unesco.org/en>
2. UNGC: <https://unglobalcompact.org/>

List of acronyms and abbreviations

ÅAU	Åbo Akademi University
BEMIP	Baltic Energy Market Interconnection Plan
CBD	Convention on Biological Diversity
CO₂	Carbon Dioxide
DEA	Danish Energy Agency
DCEE	Department of Climate, Energy and the Environment (Government of Ireland)
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EU	European Union
GOWA	Global Offshore Wind Alliance
GWEC	Global Wind Energy Council
HBL	Hydrogen Backbone Link
HSE	Health, Safety, and Environmental
ICPC	International Cable Protection Committee
ILK	Indigenous and Local Knowledge
IPLCs	Indigenous Peoples and local communities
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Electricity
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MSP	Marine/Maritime Spatial Planning
NCEA	Netherlands Commission for Environmental Assessment
NEPA	National Environmental Policy Act
NID	Nature Inclusive Design
NZTC	Net Zero Technology Centre
OCEaN	Offshore Coalition for Energy and Nature
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
OW	Offshore Wind
PPA	Power Purchase Agreement
SEA	Strategic Environmental Assessment
SESA	Strategic Environmental and Social Assessment
SIDS	Small Island Developing States
UFC	Universidade Federal do Ceará (in Portuguese) / Federal University of Ceara
UNCLOS	United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change

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1. Introduction

1.1 Background and rationale

MSPglobal is a joint initiative by UNESCO's Intergovernmental Oceanographic Commission (IOC) and the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE). Its mission is to develop and implement international guidelines on marine/maritime spatial planning (MSP) as policy tools for advancing global ocean governance and achieving the 2030 Agenda, particularly SDG 14.2, which focuses on sustainably managing and protecting marine and coastal ecosystems. MSPglobal supports the implementation of the Joint Roadmap to accelerate MSP processes globally (MSProadmap), adopted by UNESCO-IOC and DG MARE³.

During its first phase (2018-2021), MSPglobal developed an international guide on MSP (UNESCO-IOC and European Commission, 2021) and performed two regional pilot projects in the West Mediterranean and Southeast Pacific. In its second phase, **MSPglobal 2.0** (2023-2025) aims to build a larger, more skilled network of practitioners and stakeholders to support MSP. This includes the co-development of tools such as new methodologies, assessments, good practices, toolboxes, and complementary guidelines. Such publications have benefited from the organisation of online and face-to-face events where MSP practitioners and stakeholders are invited to share experiences.

In fact, the UNESCO-IOC has played the role of bringing together the scientific community, the governmental decision-making system, and a broader set of stakeholders and rights-holders to promote sustainable ocean planning and management, including MSP (UNESCO-IOC and European Commission, 2021).

MSP requires that planners are familiar with the key characteristics of the socio-ecological system and maritime sectors that will be planned. The prioritization of offshore wind (OW) energy development is a rapidly growing trend around the world, as governments seek to incorporate this technology into their strategies to meet climate targets (GWEC, 2021). This OW rush adds additional urgency to MSP processes, which need to manage potential conflicts between this growing industry and other sectors and local

communities, while also trying to avoid further impacts on marine ecosystems and biodiversity.

Ensuring coexistence between OW and other maritime activities is central to an effective MSP process. In fact, lessons learned from established OW markets show that MSP significantly helps to reduce risks surrounding the OW sector (World Bank Group, 2021).

The Volume 1 of this publication is mainly intended for MSP practitioners and their respective government agencies, those who have the mandate to conduct a holistic MSP, to become more familiar with OW in order to ensure that ecosystem-based principles are applied, human rights are respected and economic interests considered when planning this sector.

1.2 Objectives

In this framework, with the overarching goal to achieve a better integration of all maritime sectors within the MSP processes worldwide, MSPglobal aims to develop guidance on engaging the OW sector in MSP initiatives. This is especially relevant since OW is often considered a driver for developing MSP in many countries (Spijkerboer et al., 2020). This aligns with the goal of mitigating potentially harmful interactions between OW development and the marine environment.

The main objective of this publication is to provide guidelines for MSP practitioners and OW experts on effectively integrating the OW sector into MSP processes. To do so, the publication is structured into two volumes, explained below.

1.3 Methodology

To develop this publication and achieve the stated objectives, the MSPglobal team relied on the expertise of selected professionals that expressed interest in contributing, coupled with a review of relevant literature. This publication is the result of three expert dialogues, one joint workshop and a consultation review process. It

3. DG MARE: https://commission.europa.eu/about/departments-and-executive-agencies/maritime-affairs-and-fisheries_en

also builds upon the proceedings of the 6th International MSPforum that was held in Bali (Indonesia), in October 2024.

This publication is structured into two volumes as follows:

- **Volume 1 – Basic concepts:** provides a comprehensive overview of the OW sector including its historical development, key definitions, regulatory frameworks, and the typical OW lifecycle. With marine spatial planning in mind, it examines technical aspects of the sector, from turbines to site suitability criteria and data requirements. It also outlines the interactions of OW with the environment, with the social context, and with other maritime activities based on environmental and social assessments tools. The aim is to understand the path towards coexistence.
- **Volume 2 – Good practices:** Focuses on the MSP process itself and details the challenges faced in integrating the OW sector within its scope. It provides

recommendations for both MSP practitioners and OW experts based on the MSP six phases described in the *“MSPglobal International Guide on Marine/ Maritime Spatial Planning”* (UNESCO-IOC and European Commission, 2021):

1. Setting the scene
2. Designing the planning process
3. Conducting assessments for planning
4. Developing the marine spatial plan
5. Enabling implementation of the marine spatial plan
6. Monitoring, evaluation, and adaptation of the process and the marine spatial plan

By considering sector-specific considerations and good practices, this publication supports fostering a balanced and integrated approach to OW development within the context of MSP.



2. Basic concepts of the offshore wind sector

2.1 Historic overview, market trends and skills requirements

Harnessing wind power by humans began on land centuries and millennia ago to push boats along the Nile, for grinding grain in the Middle East, and for pumping water in China (Möllerström et al., 2025). Through mechanisms perfected with time, from European mills with single rotor and a horizontal axis to American multi-bladed mills with a vertical axis, wind energy slowly advanced to become the electricity generating wind turbines we know today (Iberdrola, 2025). The first windmill for electricity production was built in Glasgow (Scotland) in 1887, and the world's first megawatt wind turbine was built in Vermont (United States of America) in 1941 (Gipe and Möllerström, 2022).

While onshore energy generated electricity from turbines installed on land, the search for stronger and more consistent wind sources motivated the transition to offshore wind (OW) energy. With limited available lands and abundant wind resources available in the open ocean, the industry started moving towards OW power installations in the 1970s, amid growing concerns about the finite fossil fuel resources and environmental impacts. The first OW farm was installed in Denmark in 1991, demonstrating the potential to harness the wind's energy beyond land (TEC, 2023; Andrew, 2019). Since then, wind energy evolved to become the renewable energy with the most installed capacity worldwide (GWEC, 2024).

The OW energy sector has expanded rapidly, helped by reduced installation costs and increased efficiency (IRENA, 2019; Wiser et al., 2021). Compared to land-based projects, OW offers advantages such as greater available space for energy generation, higher wind speeds, and reduced turbulences (Contreras Montoya et al., 2021). As such, global offshore wind capacity is projected to increase nearly eightfold by 2030 (IRENA and GWEC, 2023).

Currently, the industry remains concentrated in Europe and China, where strong policy support, advanced infrastructure, and established supply chains have driven growth. As of April 2025, China led with 138 operational OW farms, followed by the United Kingdom (51), Vietnam (42), Germany (32), Netherlands (21) and Denmark (16)

(Statista, 2025). Besides China, Europe remains a leader in OW deployment, with recent geopolitical developments further accelerating renewable energy transitions. Key players include the United Kingdom—home to the world's largest wind farm project (Dogger Bank Wind Farm, 2025)—Denmark, Germany, Ireland and Italy (IRENA, 2024).

New OECD markets and developing nations are increasingly demonstrating potential for offshore wind development. Emerging markets mainly in Southeast Asia, Central Asia, the Middle East, and North America are setting ambitious targets. Notable growth is expected in Australia, Brazil, China, India, Japan, Kenya, Saudi Arabia, Republic of Korea, and the United States of America (GWEC, 2024). By 2050, Asia is expected to dominate the sector, followed by Europe and North America (IRENA, 2019).

From a regional perspective, Latin America and the Caribbean have the highest OW potential, while favourable conditions also exist in the Black Sea and the Caspian Sea (ESMAP, 2025). Africa's offshore renewable energy potential varies significantly. Coastal Africa's data show high technical potential for OW. Cabo Verde has the strongest wind resources among African Small Island Developing States (SIDS), while Eastern and Southern Africa also hold promising opportunities, particularly in the Western Indian Ocean (African Development Bank, 2021).

Despite these opportunities, challenges remain in emerging markets, including the need for clear policy frameworks, infrastructure investment, and access to financing (ESMAP, 2019). Additionally, disruptions in supply chains, rising raw material and labour costs as well as geopolitical uncertainty continue to pose barriers to OW development (Wood, 2023). By addressing these challenges, OW can become a significant driver of sustainable energy transitions worldwide.

The design and deployment of OW infrastructure require expertise that span multiple disciplines, including oceanography, foundation engineering, structural engineering, and marine civil engineering (Tolon and Ural, 2012). However, achieving national OW targets presents a significant challenge due to skill shortages in key areas of the industry.

A study conducted in Ireland assessed employment opportunities and identified a substantial gap in skills availability, with 33 out of 42 required job roles facing shortages (BVG Associates, 2024a). The study analysed training and qualification requirements across the different OW project phases and provided recommendations for stakeholders to address these gaps (BVG Associates, 2024b). The need for senior and environmental management skills during development and operational phases is underscored, with a particular focus on specific offshore experience.

In the development and project management phase, there is a shortage of senior management, electrical, and engineering expertise. Additionally, a lack of offshore experience has made it difficult to fill requirements of environmental impact assessment (EIA) as well as environmental management roles, as skills from onshore industries do not easily transfer offshore.

The manufacturing phase is also affected by a global shortage of skilled trade workers, alongside specific offshore qualifications and construction management expertise. Last, during the operations, maintenance, and service phase, the demand for maritime training is expected to increase, with noted shortages in offshore health and safety expertise as well as electrical skills.

Addressing these capacity development needs requires coordinated efforts between governments, industry, and educational institutions to expand specialized training programs and facilitate workforce transition to the OW sector.

2.1 Life cycle of the offshore wind sector

Similar to any large-scale industrial development, the OW sector follows a structured series of development phases, each requiring extensive planning, regulatory approvals, financing and technical execution. A typical OW project goes through key milestones such as **leasing** (the process of making seabed available for commercial-scale OW projects), **consenting** (granting permission to construct and operate), **financial closing** and **installation phases** (The Crown Estate, 2022; Wind Europe, 2021). Looking beyond these basic steps is an entire lifecycle that reveals much more complexities. **Table 1** presents an overview of the main phases for OW development and relevant aspects for planners.



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Developing an OW farm is a long-term process, typically ranging from 7 to 11 years from the initial planning to commissioning. This is significantly longer than onshore wind projects which take 4 to 8 years (Iberdrola, 2024). Once operational, an OW farm can have a lifespan of over 30 years (RenewableUK, 2020).

The most time-consuming step is generally the **consenting process**. In fact, one of the main barriers hindering the development of renewable energy is the lengthy permitting procedures. In France, for example, approving time for OW installation can extend up to 11 years (European Court of Auditors, 2023), whereas in the Netherlands the permitting procedure between OW site tender and commissioning can take only four and a half years (Hughes et al., 2024). Different regulatory models influence these consenting periods and are presented in **Chapter 3.3**.

Table 1
Offshore wind sector lifecycle and description.

(Sources: Chipindula et al., 2018; Renewable UK, 2020; Caledonia Offshore Wind Farm, 2024; Tolon and Nural 2012; Wind Europe, 2021; Green Tech Skillnet, 2025; WWF-France, 2019; DHI, 2021)

OW phase	Description	For planners to consider
Planning and scoping	<ul style="list-style-type: none"> Leasing and tendering process Site selection 	<ul style="list-style-type: none"> In a plan-led approach, integrating ecosystem-based planning where relevant Early-stage stakeholder engagement can improve project acceptance
Development and siting	<p>Site feasibility assessment:</p> <ul style="list-style-type: none"> Mapping enabling conditions and constraints Identifying social and environmental sensitivities Evaluating risks (related to extreme weather, geological conditions and socio-economic impacts) <p>Project development:</p> <ul style="list-style-type: none"> Selection of technologies and engineering solutions. Planning of onshore grid connections Ensuring infrastructure and hosting ports can support OW development <p>Data collection and environmental assessments:</p> <ul style="list-style-type: none"> Bathymetric and wind speed assessments Geophysical and geotechnical surveys Onshore and onshore environmental and ecological surveys Hydrological surveys. <p>Consenting process:</p> <ul style="list-style-type: none"> Conducting public consultations Submitting consent applications Obtaining necessary permits 	<ul style="list-style-type: none"> Aligning project design with MSP processes. Avoiding military zones, maritime traffic routes, ecologically sensitive areas... Designing mitigation measures to address environmental impacts Understanding the different consent processes.
Pre-construction	<p>Project readiness:</p> <ul style="list-style-type: none"> Finalizing detailed design plans Developing a construction strategy <p>Logistics and infrastructure:</p> <ul style="list-style-type: none"> Preparing ports, storage and transportation facilities for the construction phase <p>Financial and supply chain preparation:</p> <ul style="list-style-type: none"> Establishing contracts with supply chain companies Securing financial closure 	<ul style="list-style-type: none"> Multidisciplinary collaboration for infrastructure optimisation
Construction	<p>Construction, transport and installation of:</p> <ul style="list-style-type: none"> Wind turbine components and foundations Offshore and onshore substations Submarine cables Connections between OW farms, transmission system and onshore grid. <p>Safety and security:</p> <ul style="list-style-type: none"> Implement Health, Safety, and Environmental (HSE) management plans Ensuring workforce safety 	<ul style="list-style-type: none"> Implementing mitigation measures to minimize construction impacts on the marine environment.

Operation and maintenance	<ul style="list-style-type: none"> • Regular maintenance and repairs to ensure reliability and safety • Monitoring the system's performance, its infrastructure and environmental impacts • Exploring remote monitoring and digital solutions (digital twins, AI integration, predictive maintenance...) 	<ul style="list-style-type: none"> • Implementing mitigation measures to minimize operational impacts on the marine environment.
Decommissioning or repowering	<p>End of life strategies:</p> <ul style="list-style-type: none"> • Upgrading or repowering of facilities • Decommissioning of facilities <p>Regulatory compliance and environmental responsibility:</p> <ul style="list-style-type: none"> • Ensuring compliance with decommissioning regulations (for example the OSPAR convention, which is the foundation to the decommissioning plans for all OW farms in the North Sea) • Conducting environmental assessments • Restoring the site 	<ul style="list-style-type: none"> • Conducting environmental surveys can determine co-existence between OW infrastructure and marine ecosystem/ habitats.
Disposal and reuse	<ul style="list-style-type: none"> • Dismantling • Recycling and repurposing turbine components and submarine cables. 	<ul style="list-style-type: none"> • Evaluating disposal methods and scenarios • Explore repurposing opportunities



3. Regulatory and legal frameworks for offshore wind sector

3.1 Global offshore wind policy landscape

The global demand for offshore wind (OW) energy is driven by the momentum led by the UNFCCC and its Paris Agreement, as nations prioritize sustainable solutions to tackle climate change and enhance energy security. Renewable energy sources with low carbon footprints are

seen as essential solutions to address air pollution, advancing energy access, and reducing greenhouse gas emissions (IRENA, 2019). At COP28 in 2023, world leaders renewed commitments to triple renewable energy capacities by 2030, emphasizing the urgency of transitioning to clean energy systems (GWEC, 2024). **Table 2** presents a timeline of key international frameworks and guidelines to be considered while planning for OW.

Table 2
Timeline representing key global frameworks and guidelines relevant to renewable energy and offshore wind.

(Source: Elaborated by author)

Framework	Relevance to OW energy
United Nations Convention on the Law of the Sea (UNCLOS⁴) (1982; entered into force in 1994)	Defines maritime zones and governing rights of coastal states in the exclusive economic zones, including wind energy production (Article 56)
ESPOO Convention⁵ on Environmental Impact Assessment in a Transboundary Context (1991; entered into force in 1997)	Requires SEAs for projects that may have transboundary environmental effects through the Strategic Environmental Assessment protocol ⁶ (2003), mentioning wind farms (Annex II).
Convention on Biological Diversity⁷ (CBD) (1992; entered into force in 1993)	Mandates the conservation of marine biodiversity through the Jakarta mandate on Marine and Coastal Biological Diversity (1995), the Aichi Biodiversity targets 6 and 11 —2010, and the Kunming-Montreal Global Biodiversity Framework—2022 to protect at least 30% of marine areas by 2030.
United Nations Framework Convention on Climate Change (UNFCCC⁸) (1992; entered into force in 1994)	Provides the international frameworks for reducing greenhouse gas emissions (GHGs) through the Kyoto protocol ⁹ (1997) and the Paris Agreement ¹⁰ (2015) encouraging renewable energy and low-emission energy systems.
Energy Charter Treaty¹¹ (1994; entered into force in 1998)	Establishes a legal framework for cross-border energy investments, trade, and transit, mentioning renewable wind energy sources (Article 1 (5))
2030 Agenda for Sustainable Development¹² (2015)	Provides a global framework for sustainable development, supports climate action through its SDG ¹³ and promotes renewable energy expansion and development through its SDG 7: Affordable and Clean Energy.

4. UNCLOS: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

5. ESPOO Convention: https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4&chapter=27&clang=_en

6. Strategic Environmental Assessment protocol:

https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4-b&chap-ter=27&clang=_en

7. CBD: <https://www.cbd.int/convention>

8. UNFCCC: <https://unfccc.int/>

9. Kyoto Protocol: https://unfccc.int/kyoto_protocol

10. Paris Agreement: <https://unfccc.int/process-and-meetings/the-paris-agreement>

11. Energy Charter Treaty: <https://www.energycharter.org/fileadmin/DocumentsMedia/Legal/ECTC-en.pdf>

12. 2030 Agenda: <https://sdgs.un.org/2030agenda>

This current momentum is further supported by international frameworks governing environmental parameters, as well as by international coalitions which aim to accelerate OW deployment. Initiatives such as the International Renewable Energy Agency's (IRENA) energy transition strategies, highlight a unified effort by governments, industry, and global organizations to position OW as a key component for climate action.

Forming industry-led or nonprofit coalitions contributes to knowledge exchange and guidelines production. **Table 3** outlines key organisations shaping the OW narrative globally. These collaborations can play a role in the MSP processes, facilitating access to knowledge, expertise and key players of the sector.

Table 3
Global partnerships and collaborations relevant to offshore wind sector.

(Source: Elaborated by author)

Title	Type of collaboration
Global Offshore Wind Alliance (GOWA¹³)	Public-private partnership
Global Wind Energy Council (GWEC¹⁴)	Industry-led association
International Energy Agency (IEA¹⁵)	Intergovernmental organization
International Renewable Energy Agency (IRENA¹⁶)	Intergovernmental organization
Ocean Renewable Energy Action Coalition (OREAC¹⁷)	Industry-led initiative
Renewable Energy and Energy Efficiency Partnership (REEEP¹⁸)	Public-private partnership
United Nations Global Compact (UNGC¹⁹) Offshore renewables working group, Ocean Stewardship coalition²⁰	UN-led corporate sustainability initiative
World Forum Offshore Wind (WFO²¹)	Industry association
Wind Energy-Environmental Research and Engagement Network (WREN²²)	International research collaboration
World Wind Energy Association (WWEA²³)	International non-profit association

13. GOWA: <https://www.irena.org/Energy-Transition/Partnerships/GOWA>

14. GWEC: <https://www.gwec.net/>

15. IEA: <https://iea-wind.org/>

16. IRENA: <https://www.irena.org/>

17. OREAC: <https://www.oreac.org/>

18. REEEP: <https://reeep.org/>

19. UNGC: <https://unglobalcompact.org/>

20. Ocean Stewardship coalition: <https://unglobalcompact.org/take-action/ocean>

21. WFO: <https://wfo-global.org/>

22. WREN: <https://tethys.pnnl.gov/about-wren>

23. WWEA: <https://wwindea.org/>

3.2 Regional offshore wind policy frameworks

OW deployment often serves as a driver to develop MSP but also to enhance infrastructure and sustainable development objectives. This is reflected in the evolution of policies in the EU, for example, that address grid and energy network connections but also integrate renewable energy considerations withing broader planning and environmental regulations (**Table 4**).

The 2022 regulation on Trans-European Energy Networks stipulate in Article 14 (1) that “*member states shall conclude a non-binding agreement to cooperate on goals for offshore renewable generation to be deployed within each sea basin by 2050, with intermediate steps in 2030 and 2040, in line with their national energy and climate plans, and the offshore renewable potential of each sea basin.*” This led to the development of five EU sea basin initiatives for offshore grids, which aim to integrate transport, communication and energy infrastructure while minimizing use of space as well as social, economic, environmental, climate and financial impacts (Eur-Lex, 2022).

Table 4
European Union policies relevant to offshore wind sector.

(Source: Elaborated by author)

Year	Policy
1992	Directive 92/43/EEC – Habitats Directive
2001	Directive 2001/42/EC – Strategic Environmental Assessment (SEA)
2008	Directive 2008/56/EC – Maritime Strategy Framework Directive
2009	Directive 2009/28/EC - Renewable Energy Directive (RED I)
2009	Directive 2009/147/EC - Birds Directive
2011	Directive 2011/92/EU - Environmental Impact Assessment (EIA) (amended by Directive 2014/52/EU)
2013	Directive 2013/30/EU - Offshore safety Directive
2013	Decision 1386/2013/EU - 7 th Environmental Action Programme
2014	Directive 2014/89/EU - Maritime Spatial Planning (MSP)
2018	Directive 2018/2001 - Renewable Energy Directive (RED II)
2019	Directive 2019/944/EU - Electricity Directive
2019	European Green Deal (COM/2019/640)
2020	EU Strategy on Offshore Renewable Energy (COM/2020/741)
2021	Regulation (EU) 2021/1118 - InvestEU Programme
2021	Regulation (EU) 2021/1119 - European Climate Law
2022	Regulation (EU) 2022/869 - Trans-European Energy Networks (TEN-E) Regulation
2023	Directive 2023/2413/EU - Renewable Energy Directive (RED III)
2023	EU Grid Action Plan (COM/2023/757)
2024	Regulation (EU) 2024/1991 - Nature Restoration Regulation

Regional energy cooperation mechanisms help advancing OW development but also MSP. These collaborations address transboundary challenges, optimize resource use and seek to harmonize policies by encouraging coordinated planning efforts across borders. Examples such as the Celtic Interconnector project that establishes a cross-border

underwater electricity link between Ireland and France demonstrate how submarine cable route for OW integration will require coordinated spatial planning to minimize conflicts with other marine uses (EirGrid, 2025). In the Baltic Sea, the eight countries adopted a work programme for OW development, establishing the BEMIP²⁴ offshore wind

24. BEMIP: https://energy.ec.europa.eu/topics/infrastructure/high-level-groups/baltic-energy-market-interconnection-plan_en

working group setting yearly priorities such as coordinating offshore grids, cooperating with the HELCOM VASAB MSP Working Group to coordinate environmental assessments for OW and MSP, cooperate on enabling financing, and accelerating offshore wind projects and permitting.

Beyond cooperation projects, established partnerships between different types of stakeholders provide knowledge exchange platforms and joint infrastructure planning across sea basins and jurisdictions. **Table 5** presents additional examples of such partnerships, illustrating the diverse types of collaborations shaping the offshore wind sector at regional levels.

Table 5 Examples of regional partnerships and collaborations relevant to the offshore wind sector.

(Source: Elaborated by author)

Title	Type of collaboration
Asia-Pacific Economic Cooperation Energy Framework (APEC ²⁵) Energy Working Group	Intergovernmental political group
North Sea Wind Power Hub programme ²⁶	Multinational infrastructure initiative
Offshore Coalition for Energy and Nature (OCEaN) ²⁷	Multi-stakeholder coalition (industry, NGOs, and policymakers)
Ocean Renewable Energy Action Coalition (OREAC ²⁸)	Industry-led initiative
Wind Europe ²⁹	Industry association and advocacy group

3.3 Country specific approaches to offshore wind

Understanding countries' differences in terms of MSP readiness is important, distinguishing between countries that do not have an established integrated planning framework and those that have an existing MSP framework. In certain cases, OW development drives the process for MSP, while in other cases OW sectoral plan is integrated within the MSP. Considering these differences helps to have a case specific tailored approach rather than a one size fits all.

There are different **OW development models**: plan-led (such as the case of most European countries whereby sea areas have been designated in MSP), and developer-led (such as the case of mature OW markets like United Kingdom and Denmark) (AARC, 2023; Hughes et al., 2024). In the Asian market, the Republic of Korea and Vietnam use a developer-led open-door approach to siting, whereas Japan and China use a centralised process through zone designation (Hughes et al., 2024).

There are **two main permitting models** for OW development: the centralised models —where the government carries out all the environmental and social impact assessments, conducts site feasibility surveys, engages with stakeholders and provides consent for OW development— and the decentralised model —where the developer holds responsibility to obtain consents and permits following feasibility and assessment studies. Some countries adopted hybrid approaches, combining elements from both models (IRENA and GWEC, 2023). Below are a few examples that illustrate possible development and permitting configurations.

To accelerate the permitting process, several European countries adopted a 'one-stop-shop' approach for OW licencing, for instance. The 'one-stop-shop' model coordinates with the several public authorities, which are consulted for every project, and interfaces with global stakeholders and the offshore project developers (as single entities of a consortium of companies). This allows for a streamlined permitting process and for an accelerated OW deployment process (IRENA and GWEC, 2023; DEA, 2025).

25. APEC: <https://www.apec.org/groups/som-steering-committee-on-economic-and-technical-cooperation/working-groups/energy>

26. North Sea Wind Power Hub: <https://northseawindpowerhub.eu/>

27. OCEaN: <https://offshore-coalition.eu/>

28. OREAC: <https://www.gwec.net/policy/offshorewind/oreac>

29. Wind Europe: <https://windeurope.org/>

Denmark's government, a pioneer in OW development since 1991, drew on its early experience and developed the "Danish Act on the Promotion of Renewable Energy". This legislation sets the conditions for OW farms, requiring developers to obtain three licences: i) a license to carry out preliminary investigations; ii) a license to establish the OW turbines; and iii) a license to exploit wind power for a certain number of years, and an approval for electricity production. The Act mandates the Danish Energy Agency (DEA) to oversee the entire OW development process. The DEA established the concept of a 'one-stop-shop' for OW development to act as a single national point of contact for all permitting needs but also granting licences to repower or decommission. This process requires performing an environmental impact assessment (EIA), which follow specific guidelines also developed by the DEA (DEA, 2025).

As for obtaining permits, Denmark has two different procedures: tendering and open-door. The DEA assesses requests for pre-qualifications in the tendering process taking into account economic, financial, technical and professional capacity. It appoints the concession winner in the end. In the open-door procedure, the DEA consults with other government bodies to ensure no major public interests could block the implementation of the project, and later determines what the EIA should include, before granting the licence. Local consultations with fishermen are a must, and the EIA includes an impact assessment on fisheries (Vasconcelos et al., 2022).

In Scotland, the Marine Scotland Licensing Operations Team (MS-LOT) serves as the central regulatory authority responsible for managing the consenting and licencing processes for OW energy projects, with decisions that could take as little as nine months (Marine Scotland, 2018). Developers are required to submit a supply chain development statement that outlines the anticipated level and location of supply chain impact from the proposed project (during development and consenting, construction, operation and maintenance) (Crown Estate Scotland, 2020). Moreover, there is a maximum price ceiling that aims to ensure that costs are minimised for consumers and taxpayers (Wind Europe, 2022; Vasconcelos et al., 2022).

Germany's Federal Maritime and Hydrographic Agency is responsible for the preliminary assessments of construction and operation, authorizes project applications (Hughes et al., 2024), and has a mixed tendering configuration with both a central model and an open-door procedure. In the latest tenders, non-price criteria were introduced to assess developers, such as environmental protection, contribution to skilled workforce, carbon footprint in the production of the wind turbines, existence of PPA contracts (Wind Europe, 2023). The Offshore Wind Energy Act and the existing Maritime Spatial Plan form the basis for the designation in the maritime sectoral plan for OW Energy. They identify a national and international participation process to inform and engage neighbouring countries of the plan and its potential environmental impacts (BSH, 2025; Vasconcelos et al., 2022).

In contrast, Asian markets do not have a 'one-stop-shop' approach. In countries like Japan, Vietnam, Republic of Korea, and China, OW project developers need to negotiate with multiple government agencies, leading to longer permitting timelines (Hughes et al., 2024).

In Brazil, a new OW law (2025) establishes a regulatory framework for offshore energy generation and integrates these activities into the National Energy Policy, defining how federal offshore areas can be used for electricity production. The law introduces two main granting mechanisms: (i) authorization, i.e., direct contracting based on private-sector requests; and (ii) concession, i.e., competitive bidding for government-designated areas. Projects require approval from ANEEL, Brazil's electricity regulator, and must adhere to principles such as sustainable development, environmental protection, carbon reduction, and consultation with affected communities. The law mandates environmental impact studies, ongoing monitoring, and conflict resolution for overlapping area claims. The law also mandates decommissioning requirements to restore sites after project completion (Baker McKenzie, 2025).

Table 6 presents examples of additional national offshore wind strategies from around the world.

Table 6
Examples of national strategies and plans relevant to offshore wind sector.

(Source: Elaborated by author)

Year (update)	Country	Policy
2005 (2009)	China	Renewable Energy Law
2008	United Kingdom	Planning Act
2009	China	Offshore Wind Development Plan
2015 (2023)	Netherlands	Offshore Wind Energy Roadmap
2016	Germany	Offshore Wind Energy Act
2016-2023 (2019-2028)	France	Multiannual Energy Plan
2017	Republic of Korea	Renewable Energy 3020 Implementation Plan
2017	India	National Offshore Wind Energy Policy
2018	Japan	Offshore wind promotion Act
2020	Scotland	Sectoral Plan for Offshore Wind Energy
2020	US	Energy Act
2021	Australia	Offshore Electricity Infrastructure Act
2021	South Africa	Renewable Energy Framework
2023	Vietnam	Power Development Plan VIII
2025	Brazil	Offshore Wind Law No. 15,097/2025



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4. Technical and spatial considerations of the offshore wind sector

4.1 From turbines to wind farms

4.1.1 Wind turbines

Since the 1980s, wind turbine developers have been using what is called the 'Danish concept' for their designs—three blades engineered to keep facing the wind to maximize energy production (Plate, 2024). Key components include the foundation, the transition piece, the tower, the hub and nacelle to which are attached the rotor/blades (Kaynia, 2019).

The power produced by wind is proportional to wind speed (which increases with height) and the rotor radius (**Figure 1**). Therefore, the means to produce more energy is to increase the rotor diameter and hub height (Kaynia, 2019). In fact, various predictions have expected turbines size to keep growing, reaching hub heights of over 150 m with a 250 m rotor diameter, by 2035 (Wiser et al. 2021).

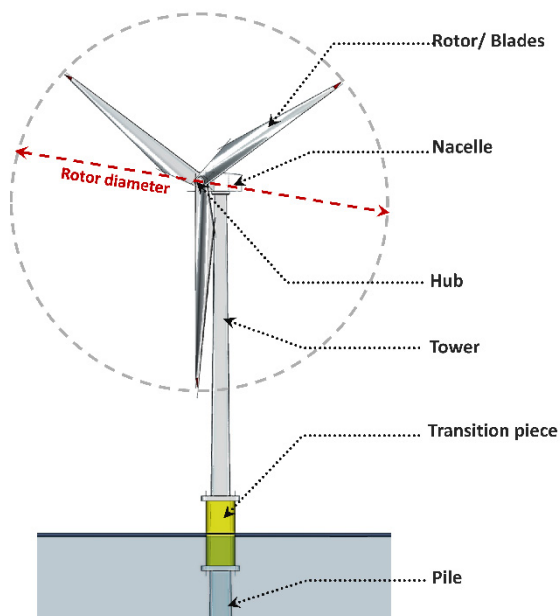


Figure 1
Illustrative representation of offshore wind turbine components (not to scale).

(Source: Adapted from Kaynia 2019).

4.1.2 Types of foundations

Water depth has traditionally been the main factor in determining the most suitable foundation typology for offshore wind (OW) projects (Sánchez et al., 2019). The OW industry leveraged decades of experience from the oil and gas industry and adapted foundation design accordingly (DNV, 2021; Edwards et al., 2023).

Additionally, advancements in floating platform technology enabled wind farms to expand into deeper waters and farther from shore, unlocking sites with higher energy potential and reducing negative visual impacts affecting seascapes and coastal communities (IAIA, 2024). Floating wind farms may alleviate some spatial conflicts by reducing competition with fishing fleets operating in shallow banks (DNV, 2023). Another advantage of floating turbines is the reduction of impact on the seabed during construction (IRENA, 2019).

Floating wind turbines technology is also expected to grow rapidly and expand into deeper seas (Maxwell et al., 2022). Seabed characteristics largely dictate the choices of anchorage structures and mooring line systems for floating OW. In some cases, shared anchors can be used to optimize space use and minimize seabed habitat disturbance. For example, the Hywind Tampen project in Norway will use 19 anchors for 11 turbines, as opposed to the earlier Hywind Scotland project that used 15 anchors on 5 turbines (Efthimiou and Mehta, 2023). This technique can reduce the spatial footprint and limits the number of anchorage points impacting the seabed habitat.

Table 7
Types of offshore wind foundations and spatial characteristics relevant for planners.

(Source: Kaynia, 2019; Van Der Valk, 2014; Keene, 2021; Sanchez et al., 2019; IRENA, 2021; Edwards et. al., 2023; IRENA, 2024)

Fixed bottom: Structures are anchored directly to the seabed and typically used in shallow to intermediate water depths (0-60 m)		
Structure type	Depth range	Characteristics
Gravity based	Up to 30 m	Uses gravity and requires no piles into the seabed. Seabed preparation is required (e.g., dredging), potentially disturbing the wind farm site. Increased footprint may lead to greater environmental impact.
Mono-pile	Up to 40 m	The most commonly used foundation for shallow waters.
Tripod	Up to 50 m	Three-legged structure. Seabed site does not require advanced preparation
Jacket	Up to 60 m	Lattice-truss structures. It can function as an artificial reef but may affect local water patterns.
Floating: Structures are used in deep waters where fixed bottom solutions are no longer viable		
Structure type	Depth range	Characteristic
Spar/multi-spar	No specific limits are defined.	Requires deep operational waters, especially for larger turbines. Large seabed footprint.
Barge	Typically, beyond 50 m	Not dependent on water depth. Large seabed footprint
Semi-submersible	(current operating floating OW farm reach up to	Not dependent on water depth. Large seabed footprint
Tension-leg platform	220 m)	Small seabed footprint. Challenging to use in areas with large tidal range

4.1.3 Wind farm infrastructure requirements

OW energy infrastructure integrates both marine and terrestrial spatial planning to connect offshore energy generation to onshore electricity grids. Typically, turbines are linked via submarine inter-array cables to export the electricity generated back to land. Offshore substations are often required for wind farms located far from shore, consolidating electricity before transmission to onshore substations. These onshore facilities connect to the national grid through terrestrial transmission and distribution networks (June Energy UK, 2025; IAIA, 2024).

In addition to energy transmission infrastructure, onshore wind port facilities play a role for the local supply chain, and they support OW development by facilitating

manufacturing, storage, assembly, construction, and operational logistics of OW farms. These ports are essential for the transport and deployment of turbines, foundations and cables, but also for long term maintenance operations (Martinez and Iglesias, 2024; Wind Europe, 2021). This interconnected system ensures efficient energy transfer from the offshore environment to onshore grids, enabling large-scale renewable energy integration into national grids.

Table 8 outlines the key land-based and marine infrastructure required for OW deployment, illustrating the connection between the OW farms and onshore energy systems.



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Table 8
Ancillary infrastructure needed for offshore wind

(Sources: June Energy UK, 2024; IAIA, 2024; UNESCO, ICCROM, ICOMOS and IUCN, 2025)

Land		Marine			
Terrestrial transmission and distribution network	Transformer/ converter station	Onshore substation (if needed)	Offshore connection	Offshore substation (if needed)	Wind turbines/ Wind Farm
The distribution system that transmits the electricity from a wind farm to the users. It involves a series of electricity pylons or transmission towers, connected by multiple cables that can extend to long distances	Usually connected via cables to one or more sub-stations. It transforms the energy produced by offshore wind turbines into higher voltage electricity and feeds it into the power grid via cables.	Onshore facilities that connect to the national grid via a cable landing point onshore.	Typically, turbines are linked via submarine inter-array cables to export the electricity generated back to land.	Offshore substations are often required for wind farms located far from shore, consolidating electricity before transmission to onshore substations.	Turbines are connected with submarine inter- array cables.

Regarding spacing considerations, turbine layouts within a farm must balance energy efficiency and cost-effectiveness. Increasing spacing between turbines reduces wake losses (i.e., electric power reduction due to windspeed reduction and airflow turbulence caused by other upwind turbines), but greater spacing increases capital costs due to longer cables requirements (Svoboda, 2021; Skousen and Zonta, 2018). As such, typical turbine spacing varies between 6-8 times the rotor diameter optimizing both energy yield and infrastructure costs (Svoboda, 2021).

4.2 Expected need for space

The demand for ocean space is projected to increase fivefold by 2050, with OW expected to account for 80% of stationary infrastructure at sea, up from 15% in 2023 (DNV, 2023). China is projected to develop the largest offshore infrastructure, followed by Europe, where spatial pressures will be particularly intense in the North Sea, the Celtic-Biscay Shelf, and the Baltic Sea (DNV, 2023; WWF, 2024).

On a global scale, OW installations are expected to cover 335,000 km², an area surpassing the landmass of Poland. Fixed-bottom OW will expand from 9,000 km² in 2021 to around 242,000 km² by mid-century, while floating OW will grow from 15 km² to over 33,000 km². However, spatial competition is expected to intensify mostly in shallow waters, particularly areas under 50 m depth, where fixed-bottom OW and aquaculture projects will increasingly compete for limited marine space (DNV, 2021).

These projections underscore the growing importance of multi-sectoral MSP and emphasize the role of planners in ensuring that OW expansion does not encroach on ecologically and culturally sensitive sites, minimizing the cumulative impacts of human activities on marine ecosystems.

4.3 Information and data requirements

The development of OW farms is conditioned by multiple factors and several constraints. Site suitability and sensitivity analysis require a comprehensive understanding of both enabling conditions and limiting factors, building on environmental, social and economic data. Sources of data vary and may not always be public or accessible. Specific recommendations on data sharing are presented in a report by UN Global Compact (2023). Lists of biodiversity and social attributes datasets is available in a guide by

World Bank Group (2024). An example of environmental data log from Ireland is available online for public access (DECC, 2024).

4.3.1 Enabling physical conditions

OW development relies on a range of physical conditions that determine the site feasibility and energy generation potential. A set of enabling factors contribute to greater efficiency and lower installation and operational costs. These factors must be assessed using precise data to ensure that development aligns with technical, economic, and environmental objectives.

Wind Conditions

Wind speed is the first factor to determine a site's potential, with strong consistent winds being recommended for optimal energy production (European MSP Platform, 2018). Accurate wind speed measurements at relevant hub heights (typically 100 m) help evaluate a site's energy yield potential. Long-term wind data help predict the consistency and reliability of energy production, which is important for assessing seasonal and year-round variations (Andrew, 2019). The Global Wind Atlas³⁰ is a key resource that can help policy makers, planners identify potential high-wind areas for wind power generation.

Water depth

Bathymetric surveys and seabed mapping provide data on the underwater topography, which is a primary factor for selecting appropriate sites and adequate foundation types. With the current available technology, OW development is limited to around 60 m for fixed bottom foundations, and around 200 m depth for floating platforms (IRENA, 2021). Data is available for example on platforms such as GEBCO³¹ (Martinez and Iglesias, 2024).

Seabed characteristics

Seabed characteristics (e.g., substrate stability, porosity, and grain size) influence foundation design and turbine stability. Softer seabeds are easier for the construction of turbine foundations (European MSP Platform, 2018). Seabed sampling and various geotechnical surveys (e.g., cone penetration tests and seismic profiling) are used to evaluate these conditions (Tolon and Ural, 2012; Campanile et al., 2018; Tolon and Ural, 2012).

30. Global Wind Atlas: <https://globalwindatlas.info/en/>

31. GEBCO: <https://www.gebco.net/>

Distance to shore

The proximity of an OW project to the coast, to nearby port facilities and to demand centres affects project costs, logistics and operational efficiency. Shorter connecting cable routes reduce transmission losses and infrastructure costs, and closer port access lowers transportation costs for installation and maintenance activities (Baltic Lines, 2018; Martinez and Iglesias, 2024). However, closer distances to the shore means greater visual impact from OW, which is a major concern influencing public acceptance of OW projects, often linked to the perceived aesthetic disruption of seascapes (Teisl et al., 2014). It is also a key consideration while working with Indigenous Peoples and local

communities (IPLCs) who might be affected by the OW development (World Bank Group, 2024). In some countries, a minimum distance to shore is established (e.g., Norway's SEA has a starting point beyond 2 km to shore) (SEANSE, 2019).

Another factor influencing maintenance scheduling is the wave climate. Sea zones with high wave heights make installation and maintenance work more complicated and expensive (Dinwoodie et al., 2013; Taylor and Jeon, 2018; Martinez and Iglesias, 2024).

As such, balancing offshore distance is key to minimize visual impact while optimizing operational efficiency and reducing costs.



4.3.2 Constraints and exclusions zones

OW projects are subject to a variety of constraints and exclusion zones that seek to balance energy production with environmental and socio-economic considerations. Once areas with high energy potential are identified, the next recommended steps are mapping existing designations, installations and infrastructure to refine suitable development areas (Baltic lines, 2018).

In the North Sea, three levels of restrictions distinguish between strict exclusion zones, areas with partial restrictions, and multi-use zones where OW can coexist with other activities (Baltic lines, 2018). In the UK, the **“Whole of seabed programme”** follows a structured approach by progressively filtering out exclusion zones, restrictions and high-cost zones from key resource areas in order to finally reach prime areas of opportunity for OW development (The Crown Estate, 2023). Finland also applies the exclusionary method by identifying ‘no go’ and ‘maybe’ areas on the map as a starting point before planning (Baltic Lines, 2018).

The definition of exclusion zones varies by region. Some areas are internationally recognized such as World Heritage Sites (UNESCO, ICCROM, ICOMOS and IUCN, 2025), or reservation areas for submarine cable corridors established by the International Cable Protection Committee (ICPC³²) (CSRIC, 2014).

Other exclusion zones are defined on a national level by governments. For instance, in Spain exclusion zones include military areas, fish farms, marine protected areas, airports, ports, maritime routes (Martinez and Iglesias, 2024) and could extend to key touristic areas (Abramic et al., 2021) and diving destinations (SEANSE, 2019).

Beyond human activities, certain exclusion areas restrict offshore activities around sensitive and endemic habitats (Abramic et al., 2021) as well as main distribution areas of marine mammals (SEANSE, 2019). A list of survey techniques used to collect biodiversity data attributes is available in a World Bank Group guide (2024).

Below is a list of relevant environmental attributes that could be considered in planning for OW (World Bank Group, 2024):

- Species: Birds, bats, fish, marine mammals, sea turtles, etc.
- Natural habitats and ecosystems
- Legally protected areas and Other Effective area-based Conservation Measures (OECMs)

Finally, to assess potential risks to infrastructure, developers must collect data on geohazards and natural phenomena that could potentially damage or destroy OW turbines such as landslides, volcanic activity, earthquakes risks and their subsequent tsunamic effect, hurricanes. Tools like seismic data and geological surveys are critical for predicting the occurrence of such hazards and mitigating risks (Bhattacharya et al., 2021; Rose et al., 2012; Tolon and Ural, 2012).

4.3.3 Socio-economic data and social attributes

In addition to technical and environmental factors, collecting social and economic information is necessary for OW development, and contributes to developing projects that are not negatively impacting communities. Spatial data related to the social dimension is more challenging to obtain, especially in emerging markets, for this reason it is recommended to apply participatory co-generation methods that include key stakeholders and community actors (World Bank Group, 2024).

While examining a site’s socio-economic context and mapping coastal communities and users of the marine space, proper consideration should be given to Indigenous Peoples and local communities (IPLCs) as well as to vulnerable and disadvantaged groups that could have cultural ties with the affected marine and coastal ecosystems and livelihood dependency on its resources (World Bank Group, 2024).

Below is a list of relevant social attributes to be considered in planning for OW (World Bank Group, 2024):

- **Coastal communities:** Coastal municipalities and IPLCs.
- **Fisheries and aquaculture:** Subsistence fisheries; artisanal, small scale and industrial, commercial fisheries; artisanal, small-scale and industrial aquaculture; processing.
- **Cultural heritage:** Tangible and intangible marine and underwater cultural heritage.
- **Recreation and tourism:** Water sports, Natural tourist attractions, infrastructure and housing.

32. ICPC: <https://www.iscpc.org/>

Box 1: The Nature Conservancy's Marine Mapping online tool

An example of an online data visualisation tool is the **Marine Mapping Tool**³³ created by The Nature Conservancy to quantitatively assess marine life and habitats based on data from the **Northeast**³⁴ and **Mid-Atlantic Regional Ocean Data**³⁵ portals. Its aim is to support environmental impact assessments related to OW energy development.

The Marine Mapping Tool includes information on the marine environment's **physical features** (depth, sediment type, seabed form and key features such as potential wrecks, artificial reefs, hardbottom and corals). It also contains information on the **people** dimension which includes ports and harbours, fleets of vessels, sum of fishers' days and at-sea location of each fleet. Finally, the portal also integrates **seasonal data** on various types of marine **species** (fish, marine mammals, birds and invertebrates).

The map allows to overlay this information with bathymetric layers, OW lease areas, shipping lanes and restricted zones.

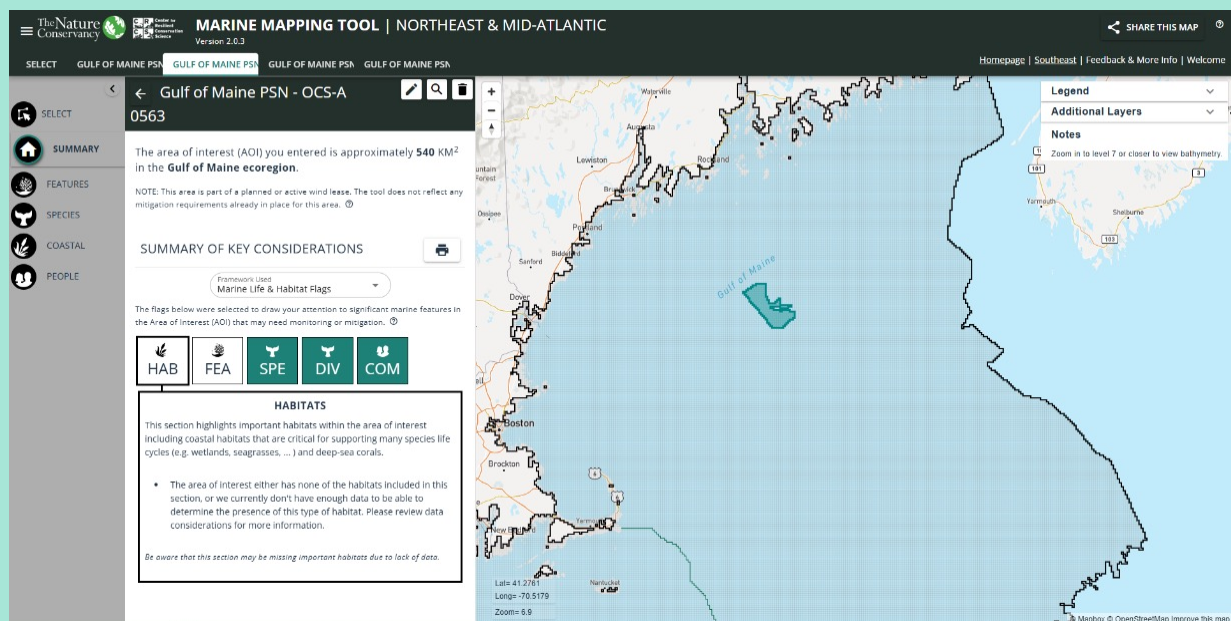


Figure 2
Marine Mapping Tool developed by The Nature Conservancy.

(Source: *Marine Mapping Tool, Northeast and Mid-Atlantic [Web application, version 2.0.3]. 2025. Design and content by M.M. Ribera. Web application by E.H. Martin. Conceptual guidance by M. Anderson, T. Jedele, and C. McGuire. The Nature Conservancy, Center for Resilient Conservation Science. <https://www.maps.tnc.org/marinemap/ne/>*)

33. TNC Marine Mapping Tool: <https://www.maps.tnc.org/marinemap/ne/#/select>

34. North East Ocean Data: <https://www.northeastoceanodata.org/>

35. Mid-Atlantic Regional Ocean Data: <https://portal.midatlanticocean.org/>



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5. Impacts of the offshore wind sector

5.1 Environmental and social assessments

While offshore wind (OW) development's key promise is to minimize environmental impacts stemming from the energy sector and reduce CO₂ emissions while ensuring energy security, it does not come without impacts.

As this relatively young sector is growing, environmental and social interactions with the OW sector are becoming more evident. Several decision support tools have been developed to assess the potential impacts of such large-scale projects and are increasingly integrating the social dimensions within their scope, depending on the development stages of the OW project. Sensitivity mapping, strategic environmental (and social) assessments (SEAs/SESAs), and environmental (and social) impact assessments (EIAs/ESIAs)³⁶ are examined and compared in this section.

Sensitivity mapping is a spatial analysis tool used to identify and visualize areas that are environmentally and socially sensitive to specific human activities or to potential hazards, such as oil spills in the case of hydrocarbon extraction (Roberts, 2019). It is done at an initial 'landscape-scale' level and assesses potential conflicts with biodiversity and key environmental features (Allinson et al., 2020). In the case of OW, it can support government planners to identify potential areas for OW development with the lowest environmental and social sensitivity (World Bank Group, 2024). These maps help ultimately inform SEA and OW spatial planning processes (EPA Ireland, 2019).

Strategic Environmental (and Social) Assessment is "a process and a tool for evaluating the effects of proposed policies, plans and programmes on natural resources, social, cultural and economic conditions and the institutional environment in which decisions are made" (IAIA, 2025). It helps identifying significant environmental and social risks for OW planning and development, assessing the scale and significance of possible cumulative impacts from multiple OW developments (IAIA, 2024). SEA's contributions enable to shape policies and plans, aligning with sustainable energy transition goals (by aligning with international

treaties), defining 'no-go' areas (by recommending areas to avoid due to high environmental and social risks) and helping to streamline EIAs (by addressing broader-scale cumulative impacts and upstream issues) (IAIA, 2024). SEA can provide the foundation for an effective MSP process by enabling critical environmental assessments, by addressing transboundary marine environmental and social concerns and OW cumulative impacts, and by establishing local and transboundary stakeholder collaboration for MSP (WWF-France, 2019).

Environmental (and Social) Impact Assessment

is "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA, 2009). Some of these assessments focus on analysing impacts on the biophysical environments, while other extend to include the social impacts. Conducting these assessments is a legal requirement under many countries' legislation. This is the case for the United States of America that established the first EIA law around the world (National Environmental Policy Act – NEPA, 1970)³⁷, the EU (EIA Directive 2011/92/EU), and China (Environmental Impact Assessment Law, 2003). The EIA approval is a prerequisite for most OW development permitting processes and therefore a condition to achieve project consent (GoBe Consultants Ltd, 2018).

Table 9 compares sensitivity mapping, SEA and EIA. Each of these tools plays a complementary role in OW planning, ensuring informed decision-making at different levels of governance and project development.

36. For the purpose of this report we will refer to the assessments using the acronyms SEA and EIA.

37. NEPA: <https://ceq.doe.gov/>

Table 9
Comparative table between sensitivity mapping, SEA and EIA.

(Sources: GRID-Arendal, 2014; Roberts, 2019; World Bank Group, 2024)

	Sensitivity mapping	SEA	EIA
Scope	Identify environmental and social sensitive areas to inform spatial planning.	Evaluate environmental and social impacts of policies, plans or programmes at a strategic level.	Assess specific environmental and social impacts of a specific project.
Stage in planning	Early stage (spatial) planning prior to site selection.	Early stage in policy and programme development to integrate environmental and social considerations.	Conducted after a specific project is proposed, as part of regulatory approval.
Scale	Broad scale or site-specific.	Broad scale.	Site-specific.
Focus	Biodiversity hotspots, heritage sites and existing maritime uses.	Cumulative and high-level environmental and social impacts.	Site-specific environmental and social impacts of a defined project.
Regulatory requirement	Often voluntary.	Required for certain policies/programmes.	Legally required for large-scale development projects under EIA regulations.
Key contribution	Identifying exclusion zones and constraint before project planning. Informs SEA.	Early warning, risk prevention of large-scale environmental and social impacts. Streamlines EIA.	Identifying environmental and social impacts and proposing mitigation strategies. If approved, leads to project consent.
Application examples	Mapping critical marine habitats space for OW planning.	SEA for a national OW energy transition strategy.	EIA for a specific OW farm project.

5.2 Environmental impacts

The environmental impacts from the OW sector vary throughout the development phases, depending on the type of OW foundation and turbines' technical components, the proposed site's characteristics and its distance to shore, and on the raw materials' supply chains. A Lifecycle assessment (LCA) allows to estimate emissions, impact on air, water, seabed resources as well as the CO₂ payback times, in order to identify which stage affects the environment the most and ultimately redesign it to minimize the negative impacts (Chipindula et al., 2018). Understanding the spatio-temporal dimensions of these interactions is a key requirement for planners. Considering the land-sea interactions, but also the three-dimensional aspect of the ocean such as the seabed, water column, water surface and the air space.

Studies show that most negative impacts occur during the construction phase, whereas impacts during the operational phase were more variable. As for the decommissioning and

the dismantling of the turbines, there is still limited research on the subject (Watson et al., 2024).

During construction and installation

Lifecycle assessment (LCA) of the wind energy industry highlights environmental impacts that could arise even before the installation and operational phases. Raw material extraction —primarily steel and cast iron, the main components of wind turbines (Verma et al., 2022 in (Morozovska et al., 2024)— occur in various locations around the globe including in poor and middle-income countries (Carrara et al., 2020). For example, a single monopile with an 8-10 m diameter for 30 m water depth may require over 1000 tons of steel for their fabrication (Pisano, 2019). A more detailed overview of material sourcing can be found in Morozovska et al. (2024).

The **mining, transportation, processing and manufacturing** of turbine components requires significant amounts of energy, water and fuel, contributing to CO₂ emissions. Compared to onshore wind, offshore installations

require higher material input, greater energy consumption, and results in higher emissions (Chipindula et. al 2018; Helman, 2021). A comparative study of onshore, shallow water and deep-water OW farms in the United States of America indicates that the most significant impact comes from material extraction and processing. Deep-water OW

construction has the highest impact contribution, followed by onshore and finally by shallow water installations. The study also shows that offshore farms have longer payback times for CO₂ and energy consumption, ranging from 6 to 17 years (Chipindula et al., 2018).



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Beyond material extraction and energy demands, the installation process can disrupt marine ecosystems. Sediment movement and physical disturbances from piling, anchor installations and the laying of turbine foundations can alter and damage seabed ecosystems and marine species' habitats, smothering benthic organisms and affecting water quality (GWEC, 2024; IRENA, 2024). Additionally, noise pollution from pile-driving and vibrations can impact marine species sensitive to sound, such as marine mammals (National Academies of Sciences, Engineering, and Medicine, 2024).

Transportation impacts are evident both on land and at sea. On land, the transportation of large turbine components places pressure on local infrastructure potentially causing road damage and necessitating upgrades to accommodate oversized loads. These unusual traffic occurrences also affect local communities (IAIA, 2024). At sea, increased working vessel movements associated with surveying and installation activities raise the risk of collisions with marine

cetaceans and pinnipeds, sea turtles and fish (Bailey et al., 2014; IAIA, 2024). Marine transportation may be a cause for the introduction of non-indigenous species, though further investigation into this topic is required (Watson et al., 2024).

These lifecycle impacts highlight the need for mitigation strategies during material sourcing, transportation, construction and installation activities.

During operation and maintenance

During its operational phase, OW energy plays a role in climate change mitigation by reducing CO₂ emissions. Studies report that expanding wind energy capacity could reduce global warming by up to 0.64 °C by the end of the century (Long et al., 2023). However, while the production of wind energy significantly reduces CO₂ emissions, wind turbines do not operate at full capacity due to downtime from harsh weather conditions, affecting overall efficiency (GWEC, 2024; IRENA, 2019).



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At a local level, OW farms might serve as a shelter for certain species, creating an artificial reef effect (Bergström et al., 2014; Degraer et al., 2020). These impacts remain context specific and are not generalised to all OW developments. Changes to local hydrodynamics can also impact the marine ecosystem, affecting species from zooplankton to large marine mammals. Increased fish and invertebrates' populations around turbine sites may expose larger predators and foraging behaviour (National Academies of Sciences, Engineering, and Medicine, 2024).

Operational impacts extend to noise pollution and physical interactions with turbines which continues to disrupt fish and marine mammals (Bergström et al., 2014), birds (Leemans and Collier, 2022; Peschko et al., 2020) and bats (True et al., 2021). Migratory species and those foraging near the water surface are particularly vulnerable to turbine collisions.

Additionally, subsea cables deployment may alter marine species behaviour (e.g., eels) and their migratory patterns (Bergström et al., 2014), and the emitted electromagnetic fields may influence marine species (Verhelst et al., 2025).

Environmental impacts resulting from floating OW activities are lower compared to the fixed bottom counterparts

as they have a reduced interface with the ocean seabed (IRENA, 2024). However, risks remain such as entanglement of marine life in debris caught on mooring lines and dynamic inter-array cables, as well as benthic habitat degradation from anchor scour and cable infrastructure (Maxwell et al., 2022).

End of life

Waste disposal is the main concern resulting from the decommissioning phase, occurring after 30-40 years of operation. While a large part of a decommissioned wind farm can be recycled, the blades account for most of the non-decomposable waste (e.g., Glass Fiber Reinforced Polymer). These often end up piling up in landfills, leading to pollution risks from hazardous materials affecting land and water (IAIA, 2024).

As such, growing interest in managing decommissioned OW turbine components has largely focused on turbine blades, as they are the most difficult to recycle (Spini and Bettini, 2024; Zhang et al., 2017). Efforts are also underway to recover and recycle subsea cables, with initiatives such as Oceanic Environmental Cables³⁸ exploring potential sustainable solutions.

38. Oceanic Environmental Cables: <https://oecops.com/>



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5.3 Social and economic impacts

In addition to environmental advantages, OW energy projects —if implemented in line with international standards— offer numerous **socio-economic benefits**, including job creation, economic growth, infrastructure development, enhanced energy security through diversified energy sources contributing to a global energy and economic resilience. OW helps governments achieve environmental targets while also fostering community benefits that build trust, ensure positive socio-economic impacts, and support the sector's long-term growth (GWEC, 2024; IAIA, 2024).

That being said, and as with any large-scale development project, OW sector poses a range of social and economic risks. From the initial stages, human rights issues are often raised regarding workers involved in the mining activities, which may occur in countries with little human rights enforcement power. Unethical mining practices, land violations and forced child labour are some of the concerns. Labor conditions during construction and operation need also to be strictly managed to mitigate accidents since the offshore conditions pose greater occupational health and safety risks (IAIA, 2024). Potential links between OW and conflict has also been explored, namely in the Global South region (Gorayeb et al., 2024).

Social opposition to OW farm projects also stems from concerns about their effects on local livelihoods, economies and cultural practices —particularly for Indigenous communities. The development of wind farms can disrupt Indigenous communities' cultural practices, as seen in La Guajira, Colombia, where the Wayúu People protested against land appropriation affecting their cultural identity. Colombia's Energy Transition Law mandates revenue-sharing within host municipalities to mitigate such conflicts (Vega-Araújo et al., 2024).

Key factors influencing social acceptance include perceptions of visual and aesthetic changes, strong place attachments, the absence of tangible benefits, the relationships with developments and external stakeholders, as well as the effectiveness of planning in addressing community interests (Haggett, 2011). Wind energy projects may lead to negative aesthetic/visual impacts, with larger turbines and their associated infrastructure disrupting natural landscapes and views and altering the natural seascape's character (GWEC, 2024; IAIA, 2024).

Additionally, key concerns among fishing communities include disruptions to commercial fishing operations, displacement of fish stocks, and uncertainties regarding access to natural resources, including fishing rights (Watson et al., 2024).



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6. (Spatial) Interactions between offshore wind and other maritime sectors

The following section explores interactions with other maritime uses and activities, highlighting existing and potential conflicts synergies with the aim to derive co-existence opportunities between OW and maritime activities.

OW is a relatively new industry finding space amongst existing other users and interests. Planning and developing applications for OW should be shaped by a thorough understanding of and engagement with relevant sector stakeholders to find the most suitable layout and siting options within technical constraints, to help minimise impact and enhance support for projects. (UNESCO-IOC and European Commission, 2021).

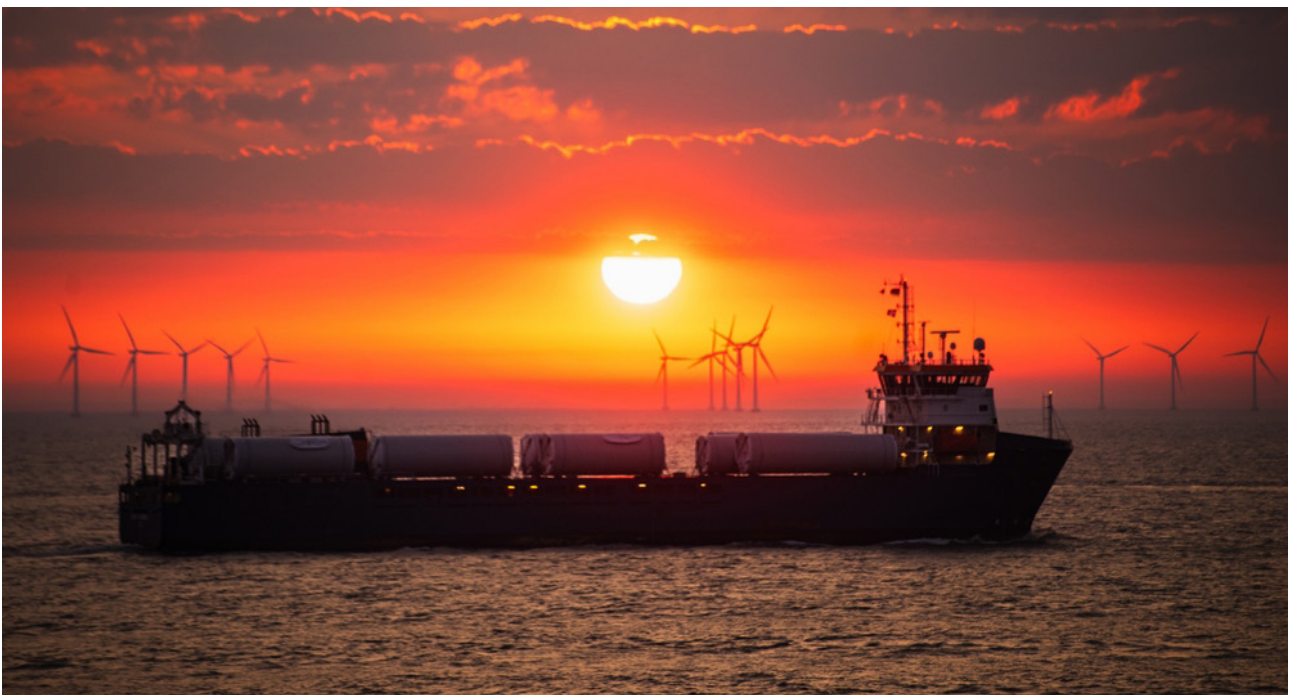
Below is an overview of the different negative (-) and positive (+) interactions, considering the marine and coastal infrastructure for each sector.

6.1 Maritime transport

(-) The presence of OW farms in the marine space creates obstacles for ships leading to longer shipping routes due to deviation efforts, as well as risks of collision due to heavier

traffic density. The interference with radar and on-board communication devices is also detrimental to navigational safety (IAIA, 2024; Mehdi, 2018).

(+) Beyond the operational role, the growth of renewable energy has become a driver for the regeneration of ports and harbours, attracting investments to upgrade and expand their facilities in order to accommodate the growing needs of the OW sector (e.g., Belfast Harbour's investments to upgrade and regenerate its facilities to support OW industry and cruise tourism (Memija, 2025). Port infrastructures support the OW industry by providing essential logistics services during both the construction and maintenance phases (Mehdi, 2018). Infrastructure expansion requires close collaboration between ports and the rest of OW value chain. Recognizing this, Wind Europe established the Offshore Wind Ports Platform³⁹ to facilitate knowledge exchange, promote best practices and bring together industry stakeholders and policy makers.



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39. Offshore Wind Ports Platform: <https://windeurope.org/policy/topics/offshore-wind-ports/>

6.2 Aviation and military defence

(-) The proximity of OW farms to military zones, airports, and zones of national security may lead to potential complications. Wind farms can interfere with electromagnetics, radar signals and telecommunications systems, including local mobile phone coverage and quality, which distorts signals and disrupts aviation (IAIA, 2024). Another critical consideration is the helicopter routes needed for OW farms operation and maintenance, which may be also factored into MSP (SEANSE, 2019).

On the other hand, recent geopolitical developments have further highlighted how political and security concerns can challenge OW farms developments. For example, in November 2024, Sweden cancelled plans for 13 OW farms in the Baltic Sea due to security concerns raised by the Swedish armed forces, particularly regarding submarine detection and potential air attacks. This decision reflects broader concerns about threats to underwater infrastructure, including OW farms and communication cables (Miranda, 2024).



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(+) As OW farms expand, their integration within national security operation requires collaboration to ensure airspace surveillance and maritime monitoring remain effective. OW farms can serve as multi-purpose platforms, supporting both military and civilian operations. They can be used for maritime and airspace surveillance, weather and pollution monitoring, and expanding maritime communication infrastructure. Such dual-use applications foster cooperation between energy developers and military planners while contributing to environmental monitoring and emergency communication systems (Son and Oh, 2024).

In the Netherlands, airspace restrictions have been implemented to reduce conflicts between military operations and OW farms. Military aircrafts are restricted to fly below 1,200 ft within a 5 NM radius of OW farms, while turbine tip heights are limited to 251 m above mean sea level. A minimum distance of 500 m between military activities and OW farms has also been established (SEANSE, 2019).

In the United Kingdom, the Ministry of Defence (MOD), in collaboration with the Offshore Wind Industry Council (OWIC⁴⁰), explored technical solutions to mitigate the impact of OW farms on air defence radar, ensuring national security while supporting OW development. The initiative assessed various technologies, including advanced radar systems, infill radars, electro-optical solutions, and radar-absorbent materials. The findings will inform future mitigation strategies, enabling OW projects to coexist with defence infrastructure while maintaining effective radar surveillance (UK Ministry of Defence, 2022).

6.3 Fisheries and aquaculture

The interactions between OW farms and fisheries/aquaculture have been increasingly explored in literature, contributing to a knowledge improvement of the interactions between species and OW farms (Bergström et al., 2014; NOAA, 2025; The Nature Conservancy, 2023; Twigg et al., 2020; Stelzenmüller et al., 2022; Van Hoey et al., 2021). Based on these studies, identified impacts range from positive to negative (**Table 10**), vary across the OW farm lifecycle, depend on the stakeholders' perspectives, and change according to the resource species in question, to their spatiotemporal variability of the four types of known or potential effects of OW on fish and fisheries (Bergstrom et al., 2014), which helps determine the scale of the impact.

40. OWIC: <https://www.owic.org.uk/>

Table 10
Offshore wind impacts on fisheries.

(Sources: Gill et al. 2020; Szostek et al. 2025)

Impact category (description)	Positive aspects	Negative aspects
Artificial reef effect (new submerged structures that attract marine life)	Creating new habitats, increasing local fish abundance, potential spillover effect on fisheries.	May alter predator-prey relationships; may introduce invasive species; may cause localised ecosystem shifts.
Fisheries exclusion (restrictions of fishing and creation of no-take zones)	May lead to stock recovery; serves as a form of marine protected area, may enhance biodiversity.	Restricts access to traditional fishing grounds, impacts livelihoods of local fishers.
Fisheries displacement (Relocation of fishing efforts to other areas)	Reduces fishing pressure in some areas, may lead to new fishing opportunities.	Increases competition in other areas, increases distance travelled to fish, creates potential conflicts with conservation and marine users.
Energy landscape effects (alteration in the marine environment through noise, electromagnetic fields (EMFs), changes in water currents and in wind wakes)	Potential benefits for some species due to altered habitats and food availability.	Disrupts fish behaviour and migration, potential physiological impacts from noise and EMFs.

(-) While these negative impacts of OW farms are shared with fisheries, the effects on aquaculture tend to be more complex. Specific challenges include infrastructure limitations (the relative permanence of aquaculture structures, risks of cage/net anchoring interference with subsea cables, potential collisions with floating structure, etc.), ecological risks (higher susceptibility to disease and parasite spread within confined farming systems), economic constraints (higher capital investment requirements, insurance difficulties), and legal uncertainties (unclear licensing frameworks for aquaculture within OW farms) (Van Hoey et al., 2021).

(+) A potential strategy to mitigate conflicts between fisheries and offshore energy development is the establishment of fishery corridors —designated areas where OW projects are prohibited — while allowing fishing vessels to operate (European MSP Platform, 2021).

Experiences of co-location integrating OW and aquaculture have been explored through various pilot initiatives across Europe (European MSP Platform, 2025a; Stelzenmüller et al., 2021). The OLAMUR project⁴¹ (Offshore Low-Trophic Aquaculture in Multi-use Scenario Realisation in North and

Baltic Seas) aimed to demonstrate solutions for integrating low trophic aquaculture (such as seaweed and blue mussel cultivation) within OW farms in three pilot sites in the North and Baltic Sea. This approach promotes multi-use planning, reduces spatial conflicts and goes in line with ecosystem-based management by selecting low trophic species. Similarly, the UNITED project⁴² tested synergies between OW farms and aquaculture. In Germany, seaweed and blue mussels were trialled, while in Belgium flat oyster aquaculture was explored. Key success factors revolved around dedicated maintenance activities, the use of remote sensing technologies and establishing strong collaborations with OW operators (Staufenberger, 2023). However, while showing potential for economically viable types of fisheries, these experiences underscore the need to account for the socio-economic and ecological trade-offs that result from co-location (Stelzenmüller et al., 2021).

41. Olamur project: <https://olamur.eu/>

42. UNITED Project: <https://www.h2020united.eu/pilots>



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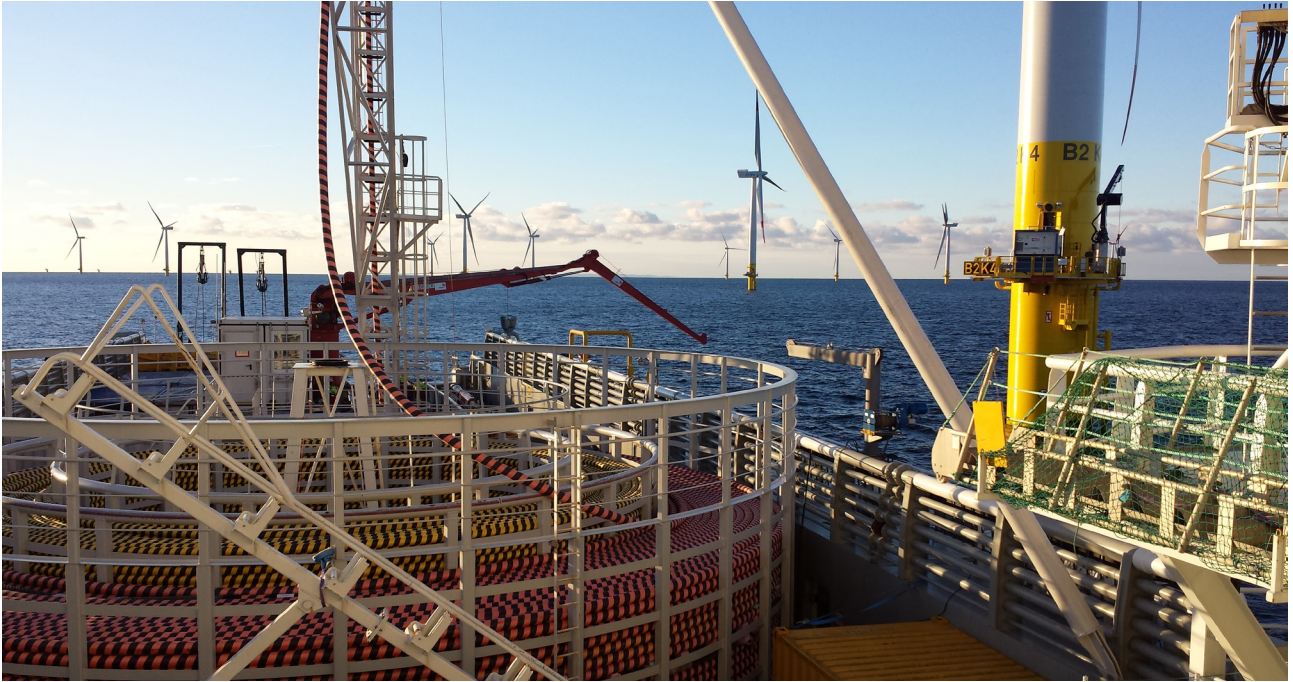
6.4 Offshore energy sector

(-) While the OW industry builds on knowledge and experience from the oil and gas sector, spatial conflicts remain with existing infrastructure. Early-stage site assessments and construction may overlap with licenced oil and gas as well as carbon storage areas, where drilling equipment and pipelines could pose challenges to turbine placement and operation. As for the operation phase, co-location conflicts can arise as both sectors require marine space for vessel navigation and servicing but also helicopter transport routes. These disputes could take up several years to solve leading to delays in consenting processes (IAIA, 2024).

(+) Despite the spatial overlaps and operations challenges, OW and oil and gas present opportunities for collaboration and innovation. One potential synergy is the electrification

of offshore oil and gas platforms using wind energy, which can reduce production costs for oil and gas operators and lowering carbon emissions (Gondal and Masood, 2019). In fact, this has been the case of the Hywind Tampen floating wind farm in Norway which became operational in 2023 (Frangoul, 2023).

Additional benefits include the utilization of similar infrastructure components, allowing both industries to align installation schedules and shared service providers for construction and maintenance, improving efficiency and reducing costs. Another area of collaboration is data sharing in overlapping project zones. Geological and geophysical surveys as well as environmental assessments are essential for OW, oil and gas, and carbon storage projects. By coordinating research efforts, developers can optimize resources and streamline permitting processes emissions (Gondal and Masood, 2019).



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(-) The main concern regarding the interaction between OW and other renewable energy development projects, especially with the growing demand for clean energy and decarbonisation, is the potential competition for space from spatially demanding infrastructure, such as the one required for wave energy (European MSP Platform, 2018).

(+) Opportunities for co-location of OW and other forms of clean energy production are growing. For instance, the potential for coupling green hydrogen production and OW farms is rapidly expanding. In Brazil, 96 OW projects planned for electricity and green hydrogen production were in their environmental licencing phase in 2024 (Gorayeb et al., 2024). In the Netherlands, the PohsHYdon project has been approved to produce green hydrogen on a repurposed oil platform, and has successfully completed its onshore testing phase in 2024 (Battersby, 2021; Habibic, 2024). In Scotland, the government's ambition to lead in offshore wind-powered hydrogen production led to the establishment of the Hydrogen Backbone Link (HBL) project. This initiative aims to integrate OW energy with large scale green hydrogen production and export, creating a pipeline network linking Scotland to Germany while utilizing existing OW infrastructure (NZTC, 2023).

Collectively, these projects demonstrate that OW farms have the potential to become hubs for green hydrogen production, offering a cost-effective, environmentally sustainable and socially acceptable replacement for fossil fuel energy, while supporting Green House Gas reduction targets (IAIA, 2024). Key lessons learnt from these initiatives

emphasize the importance of stakeholder engagement and the development of legal frameworks that can accommodate blended hydrogen (Čučuk, 2023).

6.5 Subsea infrastructure

(-) Planning conflicts often emerge between planned OW farms and existing or newly planned underwater cables and pipelines, particularly concerning placement (SEANSE, 2019), and maintenance activities.

(+) Siting solutions include defining cable corridors, safety zones, and minimum distances between cables. For instance, the ICPC recommends establishing a default 500 m exclusion zone on either side of subsea cables located in depths up to 75 m (CSRIC, 2014).

To further support coexistence between subsea infrastructure, OW and other uses, different countries have implemented specific siting measures. For example, the Netherlands requires a minimum distance of 500-750 m between OW farms and existing cables. Additionally, safety zones around cables vary across regions, with Belgium defining a 250 m buffer, while Germany enforces a 500 m distance. Parallel routing of cables is encouraged where possible, with required distances ranging from 50 m in Belgium to 200 m in Germany. If crossings are necessary, careful planning is required to mitigate risks, while anchoring is strictly prohibited to avoid potential impacts on subsea infrastructure (SEANSE, 2019).



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6.6 Tourism and recreation

(-) OW farms may affect visual aesthetics, impacting seascapes and coastal areas' attractiveness and appeal. This in return affects tourism, recreation and hospitality businesses leading to opposition for new OW developments (IAIA, 2024; European MSP Platform, 2018).

Tourism concerns have arisen in many contexts where they have had a bearing on OW decisions. For example, in 2015, the United Kingdom government rejected a proposed OW farms off the coasts of Dorset and Isle of Wight, due to concerns about its potential impact on the natural beauty of the Jurassic coast, a UNESCO World Heritage Site. The decision cited adverse effects on landscape and seascape, while local opposition argued that the project would harm tourism and the environment (BBC, 2015).

(+) While sectoral coexistence between tourism and OW may seem unlikely, several examples illustrate its feasibility and highlight its enablers. Tourism integration within OW farms can benefit from the exclusion of certain activities and takes various forms including educational and industrial tourism (e.g., guided tours promoting environmental awareness) and recreational activities (e.g., boating, fishing, kayaking and diving) (European MSP Platform, 2025b; European MSP Platform, 2018). Successful case studies from Belgium (European MSP Platform, 2025c), France (Vedettes de Bréhat, 2025) and Denmark (Lago and Zaiter, 2023), demonstrate that OW farms can contribute to tourism through a multi-use MSP approach. Additionally, integrating tourism activities and educational activities within OW sites enhances visitors' understanding of the activity's technology, its sustainability impact and as a result may contribute to increase public acceptance (Staufenberger, 2023).



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6.7 Marine biodiversity conservation

(-) OW developments often exclude existing marine protected areas (MPAs) from their scope. Interactions between OW and marine wildlife are complex, with environmental impacts occurring at various stages of the OW lifecycle. These impacts influence habitats and wildlife disturbance, affecting the seabed, water column, water surface and airspace. Details on these interactions are described in **Chapter 5.2** of this report. MSP can explore spatial combinations between OW and marine conservation, but site-specific considerations need to be assessed carefully (Hammar et al., 2016).

(+) Ensuring coexistence between marine conservation and OW development can take multiple forms. Ensuring protection occurs before siting helps avoiding detrimental environmental impacts. Applying nature inclusive design (NID) to OW structures can also minimize the negative impacts.

In the Netherlands, specifically the Borssele and Hollandse Kust wind farm zones, regulations require that permit holders actively make design and build OW farms in a way

that enhance marine ecosystems, ensuring protection of endemic species and habitats (Nordic Energy Research, 2023). Hermans et al., (2020) propose several NID strategies for OW farms including: add-on elements to turbines or substations (e.g., biohuts, cod hotels) which provide shelter for marine species, and optimized eco-friendly cable protection layers that prevent sediment erosions while fostering marine habitats. These solutions can help marine spatial planners integrate biodiversity measures into OW projects by ensuring designs supports specific target species through ecological planning.

6.8 Maritime and underwater cultural heritage

(-) Offshore developments, including OW farms, contribute to the increasing pressure on underwater cultural heritage (UCH), historically overlooked due to its 'invisible' nature. Inadequately managed large scale dredging projects have destroyed significant historic shipwrecks and submerged settlements (Kingsley, 2016).

The installation and operation of OW farms can pose significant risks to UCH. Physical damage can occur due to seabed disturbance during turbine foundation installation, cable laying, and the deployment of support structures, all of which may impact archaeological deposits, shipwrecks, and submerged prehistoric landscapes. Scouring caused by the hydrodynamic effects around turbine monopiles can lead to the erosion of sediments that have preserved historical and prehistoric remains. Additionally, exclusion zones established to protect OW infrastructure may limit future archaeological research and heritage management access to submerged sites (Walker et al., 2024).

(+) Despite these challenges, OW also offer opportunities for UCH management. The establishment of OW zones can act as inadvertent protective areas by restricting activities like bottom trawling and aggregate dredging, which are often more destructive than OW development itself.

Furthermore, best practices in environmental and heritage impact assessments have led to more effective management strategies. For example, the United Kingdom has developed guidance frameworks that require pre-construction archaeological surveys and monitoring during the project lifecycle (Ward, 2014). In some cases, collaboration between archaeologists and developers has resulted in valuable data collection on submerged prehistoric landscapes, as seen in projects within the North Sea (Walker et al., 2024). Such collaborations not only mitigate harm but also contribute to broader scientific understanding of UCH.



7. Key messages and way forward

Offshore wind (OW) development is increasingly becoming a driver for MSP, pushing planners to reconcile economic, environmental, and sectoral interests within shared marine spaces. The integration of OW into MSP requires a structured approach that considers policy alignment, spatial planning, environmental safeguards, and multi-sectoral coordination. Below are the main key messages for marine spatial planners from Volume 1:

- The OW sector infrastructure extends across coastal and marine spaces, affecting the coast, the seabed, the water column, the water surface and the airspace. As such, planners need to consider these three-dimensional connections and the land-sea interactions.
- The OW sector's phases affect the environment and the local communities differently with varying pressures. As such, planners need to account for the cumulative impacts' nuances throughout the OW lifecycle by carefully embedding environmental and socio-economic assessments within the MSP process.
- With the increasing activities in the marine space worldwide, MSP's role is to facilitate sectoral co-existence, ensuring new OW development does not disrupt existing maritime industries and socio-ecological systems.

- National climate targets and OW expansion are reshaping national and regional MSP processes. Planners must adapt their planning approaches to evolving policy landscapes and specific contexts.

While this volume has provided foundational knowledge, Volume 2 will focus on practical guidance for MSP practitioners through:

- Identifying key challenges for ow integration in MSP
- Breaking down the MSP process and its key concepts
- Presenting recommendations by incorporating OW good practices into each MSP phase

By bridging knowledge between OW and MSP, Volume 2 aims to provide actionable strategies for OW experts as well as MSP practitioners to support the effective integration of OW into marine spatial plans while fostering sustainable ocean governance.



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A photograph of an offshore wind farm at sunset. The sky is a vibrant mix of orange, red, and yellow, with wispy clouds. Several wind turbines are visible in the distance, their silhouettes against the bright sky. The sea is calm, and the foreground shows a rocky shore with some green plants and yellow flowers. A semi-transparent blue box with white text is overlaid on the lower left portion of the image.

Offshore wind (OW) development is rapidly expanding as a key component of the global energy transition, yet its integration into marine spatial planning (MSP) frameworks remains uneven across regions. To support more coordinated and sustainable planning, this publication has been developed alongside experts to present basic concepts (Volume 1) and good practices (Volume 2) for engaging the offshore wind sector in MSP processes. It aims to strengthen the knowledge, tools and collaborative capacity of planners, authorities and energy stakeholders to ensure that MSP facilitates the efficient deployment of offshore renewables while balancing environmental, social and economic objectives.

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