Maritime Spatial Planning in Europe

Discussion Paper on the Challenges and Potential Opportunities Around the Colocation of Offshore Wind Energy with Marine Protected Areas

Report for the Renewables Grid Initiative

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Cover photo: Common eider near Aberdeen Bay Wind Farm, Scotland, UK. According to Vattenfall, this wind farm prevents in excess of 134,000 tonnes of CO_2 emissions annually. © PJ Stephenson

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Introduction

Renewable energy is central to the global effort to reduce greenhouse gas emissions and tackle climate change and since the early 1990s Europe has led the way in offshore renewables, especially offshore wind energy (OWE). European countries have set ambitious national and regional targets to increase the share of renewable energy in coming years. However, OWE is only one of many demands placed on European oceans and coasts and maritime spatial planning (MSP) needs to encompass multi-use of the seascapes and the colocation of activities wherever possible and appropriate.

The European Union has committed to expand its network of marine protected areas (MPAs) to deliver regional and global biodiversity targets. In this context, an emerging literature is increasingly considering whether conservation objectives and energy generation can be colocated. This discussion paper was therefore commissioned by the Renewables Grid Initiative to explore the issues around MSP for offshore wind energy and how colocation of OWE with MPAs, OECMs (other effective area-based conservation measures) and other uses of the ocean could help or hinder European sustainability goals for energy and nature. It involved an assessment of the current policy context, status of MPAs, the impacts of OWE on the environment, case studies of OWE in MPAs, and colocation issues around other maritime activities.

Main Findings

Policy context: EU policy lacks specificity on the colocation of OWE and MPAs but allows scope for developments such as OWE in Natura 2000 sites if significant disturbance of species can be avoided or if it is in the overriding public interest. National policies on colocation of OWE in MPAs vary, with some countries prohibiting colocation and others allowing development if environmental impacts are judged to be compatible with MPA objectives. Currently, there is no clear guidance or policy on if and how an offshore wind farm can be colocated with an OECM.

Environmental impacts: Although offshore wind farms may be less damaging than many other human uses of the ocean (e.g., fishing, dredging, shipping, oil and gas exploitation), OWE nonetheless has the potential to threaten species and habitats. Colocation of OWE with MPAs can be risky, and the degree of threat posed to any given MPA will depend on the taxonomic focus and goals of that MPA. Regional differences in environmental sensitivity to human activities including OWE are also evident. Case studies with long-term data on the impacts of OWE on MPAs are difficult to find and largely inconclusive. The reef effect, reserve effect and active nature enhancement can increase some habitats and species in offshore wind farms. However, an increase in abundance of some organisms around offshore wind farms does not necessarily deliver conservation objectives, largely because the resultant species communities may differ from those found in natural habitats.

The state of MPAs: Many MPAs lack management plans and associated objectives, and many are not assigned an IUCN management category. Many European MPAs do not offer effective protection to species and habitats, due to their small size, weak enforcement of regulations, and inadequate restrictions on offtake. MPAs are not adequately integrated into MSP processes which are not fully applying the ecosystem-approach advocated by EU policy.

Knowledge gaps: There remain some key knowledge gaps around the environmental impacts of OWE and suitable monitoring and mitigation measures. Case studies of OWE colocation with MPAs need to be further studied and monitored and results and lessons shared. Reducing knowledge gaps and improving monitoring would help reduce reliance on the Precautionary Principle and allow more data-driven MSP and adaptive management.

Other maritime activities: Other human uses of the ocean, especially passive fishing, aquaculture, shipping and tourism, may provide more appropriate and less risky colocation opportunities with OWE than MPAs.

Conclusions and Recommendations

Marine protected area networks and offshore wind farms will continue to expand across Europe in coming years to attain global and regional energy and biodiversity objectives. Based on the findings of this review, several preliminary recommendations can be made to help the diverse stakeholders involved in European MSP create the enabling conditions for the colocation of sustainable economic development activities without jeopardising the conservation of the marine ecosystems upon which, ultimately, most other activities depend.

Recommendation 1: Governments and their partners need to improve the management and protection of MPAs and better integrate MPAs into maritime spatial planning, minimizing colocation with other activities.

Recommendation 2: Opportunities for the colocation of offshore wind energy with other maritime activities should be optimised through data-driven maritime spatial planning and by addressing key obstacles.

- 2a. Common definitions need to be agreed and adopted
- 2b. Stakeholder collaboration needs to be improved
- 2c. Research needs to fill gaps in knowledge that block colocation
- 2d. Pilots for multi-use zoning and multi-purpose platforms need to be expanded.

Recommendation 3: Best practices and promising innovations to reduce environmental impacts and enhance biodiversity around offshore wind farms need to be expanded by energy companies and their partners.

- 3a. Mitigation measures to reduce impacts need to be enhanced in and around all offshore wind farms
- 3b. Actions to proactively promote nature need to be enhanced in and around all offshore wind farms.

Recommendation 4: Where colocation of OWE with MPAs does occur, mitigation actions and proactive conservation efforts need to be optimized and their impacts monitored.

Recommendation 5: Systematic monitoring, research and data sharing is required to track the state of marine species and habitats in both MPAs and in and around offshore wind farms to inform MSP and adaptive management and to fill key knowledge gaps.

Acknowledgements

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While the author greatly appreciates the input he received, the findings and conclusions in the paper are his own and do not necessarily reflect the views of RGI, OCEaN or their members.

Abbreviations and Acronyms

ASCOBANS	Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas
CBD	Convention on Biological Diversity
EC	European Commission
EEA	European Environment Agency
EIA	environmental impact assessment
EU	European Union
HELCOM	Helsinki Commission
IAS	Invasive alien species
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
MSP	maritime (or marine) spatial planning
NbS	Nature-based Solutions
NGO	non-governmental organisation
NID	Nature-inclusive Design
OCEaN	Offshore Coalition for Energy and Nature
OECM	other effective area-based conservation measure
OWE	offshore wind energy
RGI	Renewables Grid Initiative
SAC	Special Areas of Conservation (Habitats Directive)
SEA	strategic environmental assessment
SPA	Special Protection Areas (Birds Directive)
TSO	transmission system operator
UK	United Kingdom of Great Britain and Northern Ireland

1. Introduction: Offshore Wind Energy and Maritime Spatial Planning

Renewable energy is central to the global effort to reduce greenhouse gas emissions and tackle climate change. Since the early 1990s, Europe has led the way in offshore renewables, especially offshore wind energy (OWE). The Baltic Sea and the North Sea have been the two main hubs of development, but renewable energy projects are expanding into other European seas.

Through the 2030 Climate and Energy Framework, the European Union (EU) set targets to reduce greenhouse gas emissions by 40% compared to 1990 levels, to increase the share of renewable energy to 32% of final energy consumption, and to improve energy efficiency by 32.5% by 2030 (EC, 2023a). However, as part of the European Green Deal, in September 2020 the Commission proposed to raise the 2030 greenhouse gas emission reduction target, including emissions and removals, to at least 55% compared to 1990 (EC, 2023b). The EU Strategy to Harness the Potential of Offshore Renewable Energy (EC, 2020b) underlines commitments to achieve the broader energy framework and the Directive on renewable energy (EU, 2018) by attaining 60 GW of installed capacity of offshore wind energy by 2030, and 300 GW by 2050, from a baseline of 12 GW in 2020. Achieving this ambitious goal "will require identifying and using a much larger number of sites for offshore renewable energy production and connection to the power transmission grid" (EC, 2020b). This will be accelerated by the REPowerEU plan (EC, 2022) which highlights offshore wind as "a significant future opportunity". Individual Member States are even more ambitious, with the sum of their national offshore wind energy targets currently standing at between 109 and 112 GW for 2030, far higher than the original EU ambition of 60 GW (EC, 2023c). This means European countries will need to scale up OWE installation almost sevenfold by the end of the decade to meet their national objectives (Janipour, 2023).

However, OWE is only one of many demands placed on European oceans and coasts. In addition to renewable energy generation (mostly wind but also wave and solar), the extraction of oil, gas, minerals and aggregates, commercial and recreational fisheries, aquaculture, shipping, tourism, military uses and other activities all vie for space in marine ecosystems. As well as using or exploiting these ecosystems, European countries strive to protect and conserve nature and contribute to global biodiversity goals (EC, 2020a). For these reasons, the EU offshore energy strategy (EC, 2020b) underlines the need for states to plan ahead, assess the environmental, social and economic sustainability of renewable energy and ensure its coexistence with other maritime activities.

The EU Directive establishing a framework for maritime spatial planning (EU, 2014) provides a means of addressing explicitly the need to plan the use of European seas. It encourages maritime spatial planning (MSP)[1] for "the effective management of marine activities and the sustainable use of marine and coastal resources, by creating a framework for consistent, transparent, sustainable and evidence- based decision-making" (EU, 2014). The purpose is "to promote sustainable development and to identify the utilisation of maritime space for different sea uses as well as to manage spatial uses and conflicts in marine areas". As well as EU policies encouraging MSP, regional seas conventions and national governments develop strategies and plans for sustainable use of their oceans.

Maritime uses of our oceans have intensified in recent decades leading to the development of the concept of multi-use (Schupp et al., 2019) and discussions on whether or not some activities can occur together or alongside each other, often referred to as colocation. The EU explicitly states that MSP "aims at identifying and encouraging multi-purpose uses" (EU, 2014). The Offshore Coalition for Energy and Nature (OCEaN) also says that "multiple use of marine areas should be considered as a tool to conciliate between conflicting interests" (OCEaN, 2021). The use of marine space need not be mutually exclusive (Vaughan & Agardy, 2020) and therefore understanding how OWE and other activities can and cannot share marine space is vital (RSPB, 2022). In this context, "an emerging

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[1] Maritime spatial planning is defined as a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives (EU, 2014).

literature is increasingly considering whether conservation objectives and energy generation can be colocated" (Thurstan et al., 2018). Several offshore wind farms[2] have already been built in marine protected areas (MPAs) and several more are planned (e.g., Sanders et al., 2017; Ashley et al., 2018; Defingou et al., 2019; Allen et al., 2020; RSPB 2023). What are the implications of colocation for European ambitions for renewable energy and conservation?

The Renewables Grid Initiative (RGI) is a unique collaboration of European non-governmental organisations (NGOs) and transmission system operators (TSOs) which promotes fair, transparent, sustainable grid development to enable the growth of renewables to achieve full decarbonisation. In the context of its Marine Grid Declaration of 2019 (RGI, 2019), RGI members and other partners support the use of MSP for marine grid activities, in accordance with the EU Maritime Spatial Planning Directive (EU, 2014). This discussion paper was therefore commissioned to understand the challenges and opportunities around MSP for OWE and how colocation of OWE with MPAs, OECMs (other effective area-based conservation measures) and other uses of the ocean could help or hinder European sustainability goals for energy and nature.

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Offshore wind turbines near Copenhagen. The world's first offshore wind farm was commissioned by Ørsted in Denmark in 1991.

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[2] Based on EU defintions, an offshore wind farm is considered to be a group of wind turbines that can cover several square kilometres of sea to harness offshore wind energy.

2. Objectives and Methods of the Review

This discussion paper is based on a review that was undertaken between January and July 2023 by an independent consultant commissioned by RGI. The review set out to identify the issues, challenges and potential opportunities around the colocation of OWE with other maritime activities, especially MPAs and OECMs. The aim was to assess the current policy context, the status of MPAs, the impacts of OWE on the environment, case studies of OWE in MPAs, and colocation issues around other maritime activities.

The consultant conducted a desk-top literature review to assess the relationship between OWE and nature conservation, as well as other uses of marine ecosystems. Documents were identified through online search engines, such as Scopus, Google and Google Scholar. A snowballing technique was used to source other literature from that uncovered. Material reviewed included not only scientific papers in books and peer-reviewed journals, but also regulatory policies and frameworks, regional strategies and monitoring plans, general and sector-specific guidelines, reports, reviews, and other documents and websites identified as relevant.

In addition, the consultant held several informal interviews with thematic experts to seek their input, identify additional information sources and benchmark findings. A draft report was shared with members of OCEaN which yielded feedback and supplementary reference material that was integrated into the final version of the discussion paper.

3. Offshore Wind Energy and Nature Conservation: Issues Around Colocation

3.1 Policy Context

The EU Biodiversity Strategy (EC, 2020a) recognises the importance of marine resources and the need to ensure creation of protected areas, restoration of ecosystems, reduction of pollution and alien invasive species, and no deterioration in threatened species and habitats. Both EU directives on maritime spatial planning (EU, 2008, 2014) advocate for Member States to take an ecosystem-based approach to MSP and establish characteristics that define "good environmental status", thereby encouraging conservation. In June 2022, the EC adopted a proposal for a new nature restoration law (EC, 2023d) which was approved (in a modified form) in July 2023 (Gentili, 2023). If and when the regulation comes into force, Member States will be expected to develop National Restoration Plans showing how they will deliver on the targets, then monitor and report on their progress. Restoration of marine ecosystems will include "restoring marine habitats such as seagrass beds or sediment bottoms that deliver significant benefits, including for climate change mitigation, and restoring the habitats of iconic marine species such as dolphins and porpoises, sharks and seabirds" (EC, 2023d).

3.1.1 Species conservation

Various international conventions identify habitats and species that need to be conserved (see Soria-Rodríguez, 2021, for a review). In the context of European seas, conservation priorities include species identified in the EU Birds and Habitats Directives (see below) and species identified by the Convention on Migratory Species and its associated agreements on small cetaceans (ASCOBANS: Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas), seals (WSSA: Agreement on the Conservation of Seals in the Wadden Sea), bats (EUROBATS: Agreement on the Conservation of Populations of European Bats) and waterbirds (AEWA: Agreement on the Conservation of African–Eurasian Migratory Waterbirds), as well as wetland sites of international importance identified by the Ramsar Convention. In addition, regional seas conventions identify priority species for conservation (e.g., OSPAR Commission, 2008a; HELCOM, 2021).

3.1.2 Marine protected areas

A protected area is "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008). A marine protected area or MPA is a globally applicable, general term to describe any protected area in the marine realm which aims to conserve nature and maintain healthy oceans (UNEP-WCMC, 2014). Impetus for MPA designation is often derived from international commitments (Vaughan & Agardy, 2020). Global ambitions for protecting nature were clarified in the Strategic Plan on Biodiversity 2011–2020 (CBD, 2010) and its so-called Aichi Targets. Aichi Target 11 called on countries to conserve by 2020 at least 10% of coastal and marine areas through "well-connected systems of protected areas and other effective area-based conservation measures" (CBD, 2010).

The post-2020 Kunming-Montreal Global Biodiversity Framework has set higher ambitions under its target 3:

> *Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures…* (CBD, 2022).

The EU Habitats Directive, adopted in 1992 (EC, 1992), and the EU Birds Directive, adopted in 1979 and amended in 2009 (EC, 2009), promote the establishment and conservation of Natura 2000 protected areas across Europe. Under the Habitats Directive (Articles 3 and 4), Member States designate Special Areas of Conservation (SACs) to ensure the favourable conservation status of each habitat type and species throughout their range in the EU. Under the Birds Directive (Article 4), the network must include Special Protection Areas (SPAs) designated for 194 particularly threatened species and all migratory bird species (see EC, 2023e). SPAs are designated according to scientific criteria, such as if they are home to at least 1% of the population of a vulnerable species or they represent a wetland of international importance for migratory waterfowl. While Member States may choose the most appropriate criteria, they must ensure that all the 'most suitable territories', both in number and surface area, are designated. In addition, the EU Marine Strategy Framework Directive of 2008 states that "the establishment of marine protected areas… is an important contribution to the achievement of good environmental status" (EU, 2008).

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MPAs are established to protect a diversity of marine life above and below the water.

Besides global and European visions of establishing coherent networks of MPAs, important work is also being carried out by the regional seas conventions: HELCOM (Baltic Sea), OSPAR (North-east Atlantic Ocean), the Barcelona Convention (Mediterranean Sea) and the Bucharest Convention (Black Sea) (EEA, 2015a). For example, OSPAR was the first regional organisation that protected marine biodiversity in areas beyond national jurisdiction. Likewise, some European states have designated national MPA networks, either to underpin domestic ambitions or to enforce regional or EU legislation. For example, for national reasons, France designates Marine Nature Parks (*Parcs naturels marins*), the Netherlands establishes reserves under the Dutch Nature Conservation Act (*Wet natuurbescherming*) and the UK designates Marine Conservation Zones. In some cases, countries also collaborate on transboundary MPAs, examples including the Pelagos sanctuary in the Mediterranean which is jointly managed by France, Italy and Monaco for the protection of marine mammals.

The EU's Biodiversity Strategy (EC, 2020a) calls for the expansion and the effective management of the EU's network of protected areas to cover 30% of the sea. At least one third of protected areas – representing 10% of the EU's sea – should be strictly protected (i.e., with no human use). Therefore, MPAs of different designations are a key tool for biodiversity conservation.

The precise goals of different MPAs vary, as does the degree to which other uses are permitted at each type of site. IUCN defines a series of categories for protected areas and MPAs, with category I being the most protected and category VI being the least protected (Box 1). In MPAs, shipping, recreation and tourism are permitted in categories II to VI, whereas renewable energy generation is only allowed in categories IV to VI (Day et al., 2019). Fishing, aquaculture, mining and dredging are only usually permitted in categories V and VI. However, as defined by the CBD's Target 3, countries need to ensure that any sustainable use in MPAs is "fully consistent with conservation outcomes" (CBD, 2022).

Box 1. Marine protected areas and management categories

Momentum for the creation of marine protected areas or MPAs increased after the first World Congress on National Parks in 1962. At the Congress, recommendations were made for governments to “examine, as a matter of urgency, the possibility of creating marine parks or reserves” and by 1970 there were already 118 MPAs in 27 countries (Humphreys & Clark, 2020). By 2021, 28.1 million km^2 (7.74%) of coastal waters and the ocean were found within MPAs and OECMs (UNEP-WCMC & IUCN, 2021). Recent trends in MPA designation include the protection of high sea areas beyond national jurisdiction, and growing recognition of the importance of protecting large-scale marine areas of more than 150,000 km^2 (Laffoley et al., 2019).

IUCN has defined different categories of protected area (Day et al., 2019):

- **Ia Strict nature reserve**: Strictly protected for biodiversity and geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
- **Ib Wilderness area**: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
- **II National Park**: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
- **III Natural monument or feature:** Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
- **IV Habitat/species management area**: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats. Extractive research is permitted, as is renewable energy generation and restoration or enhancement for other reasons (e.g., beach replenishment, fish aggregation, artificial reefs).
- **V Protected landscape or seascape**: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
- **VI Protected areas with sustainable use of natural resources**: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category of a protected area should be based around the primary management objectives, which should apply to at least three-quarters of the protected area. The management categories are applied with a typology of **governance types**, a description of who holds authority and responsibility for the protected area. IUCN defines four governance types:

- **Governance by government**: Federal or national ministry/agency in charge; sub-national ministry/agency in charge; government-delegated management (e.g., to NGO).
- **Shared governance**: Collaborative management (various degrees of influence); joint management (pluralist management board; transboundary management (various levels across international borders).
- **Private governance**: By individual owner; by non-profit organisations (NGOs, universities, cooperatives); by for-profit organisations (individuals or corporate).
- **Governance by indigenous peoples and local communities**: Indigenous peoples’ conserved areas and territories; community conserved areas – declared and run by local communities.

Marine reserves[3] are an important type of MPA in which all forms of extraction and use are prohibited. Results show that existing European marine reserves foster significant positive increases in key biological variables (density, biomass, body size, and species richness) compared with areas receiving less protection but, for marine reserves to achieve their ecological and social goals, they must be designed, managed, and enforced properly (Fenberg et al., 2012). An important step towards the protection of Europe's marine ecosystems is the establishment of marine reserves within wider-use MPAs as connected networks across large spatial scales (Fenberg et al., 2012). IUCN (Day et al., 2019) underlines the importance of strict protection no-take zones for biodiversity as well as fisheries. Currently, only 1% of Europe's seas are strictly protected (EC, 2020a), well short of the ambition of 10% strict protection.

3.1.3 Other effective area-based conservation measures

Other effective area-based conservation measure (OECM) is a term coined by the CBD (2010, 2022) which was defined with criteria in 2018 (CBD, 2018). OECMs are geographically defined areas other than protected areas which are governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic, and other locally relevant values (CBD, 2018). OECMs are meant to provide effective long-term conservation of whole ecosystems with high biodiversity value, with conservation outcomes equivalent to those of protected areas. The feature that distinguishes between a protected area and an OECM is that the former has a primary conservation objective whereas the latter delivers the effective in situ conservation of biodiversity regardless of its objectives (Maxwell et al., 2020).

Designation of OECMs offers a significant opportunity to recognise de facto effective long-term conservation that is taking place outside currently designated protected areas under a range of governance and management regimes, implemented by a diverse set of actors, including by indigenous peoples and local communities, the private sector and government agencies (IUCN WCPA Task Force on OECMs, 2019; IUCN WCPA, 2022). However, there remains a degree of uncertainty about what qualifies as an OECM and the designation process of OECMs is still unclear, especially in the marine environment (Shabtay et al., 2019).

3.1.4 Policy issues around colocation

EU policy

The EU Strategy to Harness the Potential of Offshore Renewable Energy (EC, 2020b) encourages the coexistence of OWE with activities such as fisheries, aquaculture, shipping, tourism, defence and infrastructure deployment, but it does not explicitly propose colocation with MPAs and OECMs. However, it does note that it is possible to develop sustainable economic activities in MPAs. The EU Biodiversity Strategy (EC, 2020a) simply notes the potential for fish stock regeneration around OWE, which is a fisheries management issue rather than a conservation issue. The Habitats Directive (EC, 1992) states that "any plan or project not directly connected with or necessary to the management of the site" has to be subject to an appropriate assessment if it is likely to have a significant effect on the MPA. National authorities should then "agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned" (EC, 1992).

The significance of an impact on species is important in the context of the Habitats Directive. Although the term is not defined in the Directive, later EU guidance states that in a Special Area for

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[3] Marine reserves are defined as ocean or intertidal areas that are fully protected from activities that remove animals and seaweeds or alter habitats—such as fishing, aquaculture, dredging and mining—except as needed for scientific monitoring (PISCO, 2011).

Conservation “disturbance of a species must be avoided in so far as it could be significant[4] in relation to the Directive’s objectives” (EU, 2019). Therefore, “the notion of what is ‘significant’ needs to be interpreted objectively” (EU, 2020). The EU has offered suggestions on how this might be achieved through appropriate significance assessments. “The significance assessment always needs to be underpinned by solid scientific arguments and should refer to the conservation objectives of the site” (EU, 2020). For habitats, the EU suggests significance is at least determined by quantifying the area of EU-protected habitat predicted to deteriorate compared with the total baseline habitat area and the importance of the habitat for EU-protected species. For species, impacts need to be considered at a population level to determine whether they are biologically significant (Bailey et al., 2014).

Member States will need “to take all the appropriate actions to ensure that no deterioration or significant disturbance occurs” and deterioration and disturbance caused by a project “should be assessed against the conservation objectives of the site and the conservation condition of the species and habitat types present in the site” (EU, 2019). Any projects likely to significantly affect a Natura 2000 site will therefore need to be assessed through an environmental impact assessment (EIA). However, a Habitats Directive clause allows projects in Nature 2000 sites even if they are assessed to have negative implications “for imperative reasons of overriding public interest” (EC, 1992).

The REPowerEU plan (EC, 2022) introduces the designation of go-to areas[5] for renewables that shortens and simplifies permitting. This has raised concerns that some environmental safeguards in planning may be bypassed or ignored in go-to areas (WWF EPO, 2022d). And how likely is it that countries will see current concerns about energy security arising from the war in Ukraine (EC, 2022), as well as the ongoing climate crisis (UNEP, 2021), as imperative reasons “of overriding public interest” to develop OWE in MPAs in spite of environmental concerns?

National policies

While some forms of sustainable use are permitted in some types of MPA in Europe, the level of protection or exploitation is unclear due to a lack of data (EEA, 2015a). National policies specifically on the colocation of OWE and MPAs vary. For example, in the North Sea, the Dutch government has agreed through the North Sea Agreement with stakeholders (OFL, 2020) that no offshore wind farms will be placed within Natura 2000 areas. A similar policy is followed by other Member States such as Estonia and Latvia, whereas Belgium and Germany have plans to build offshore wind farms in MPAs (WWF EPO, 2022b). According to WWF-France (2019), there are 20 proposed offshore wind farms in 14 Natura 2000 sites in Greece. In France, offshore wind farms are not deemed compatible with National Natural Reserves or National Parks but consent may be authorised in Natura 2000 sites on a case-by-case basis, and in Marine Natural Parks if the impacts are adjudged to be insignificant (Defingou et al., 2019). In the UK, offshore wind farms can be placed in MPAs and MPAs can be created around offshore wind farms if objectives are compatible (Ashley et al., 2018). The UK government’s Offshore Energy Strategic Environmental Assessment (2008-2009) recognised the potential for colocating wind farms with MPAs to reduce potential spatial conflict: “Where the objectives of the conservation sites and renewable energy development are coincident, preference should be given to locating wind farms in such areas to reduce the potential spatial conflict with other users” (DECC, 2009).

Policy on colocation with OECMs

IUCN guidelines state that environmentally-damaging industrial activities and infrastructure development should not occur in OECMs (IUCN WCPA Task Force on OECMs, 2019), and multiple-use production areas (e.g., commercial fisheries areas) should not be promoted as OECMs (Woodley et

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[4] “Deterioration of a natural habitat or a habitat of a species is not qualified by the need to be significant in relation to the Directive’s objectives, it must simply be avoided altogether” (EU, 2019).

[5] A renewables go-to area is a location designated by a Member State as particularly suitable for the installation of plants for the production of energy from renewable sources, other than biomass combustion plants (EC, 2022).

al., 2021). However, none of the reviews of OECMs to date (IUCN WCPA Task Force on OECMs, 2019; Woodley et al., 2021; IUCN WCPA, 2022) mentions renewable energy explicitly. Even so, it would seem that there are some challenges to classifying offshore wind farms as OECMs, largely because they are not likely to allow for the conservation of "specialised ecosystems in their entirety" or do not protect species through "in-situ conservation of biodiversity as a whole", as specified as necessary for an OECM by IUCN (IUCN WCPA Task Force on OECMs, 2019). Offshore wind farms with other colocated activities, such as aquaculture, presumably count as multiple-use production zones and are also likely to be excluded. However, there does not seem to be a formal process to clarify if and how an offshore wind farm could qualify as an OECM. As a result, OECMs are not yet adequately integrated into maritime spatial planning processes (Shabtay et al., 2019).

3.2 Potential Impacts of Offshore Wind Energy on Marine Habitats and Species

3.2.1 Potential negative impacts on biodiversity

While offshore wind energy offers immense potential for clean, green sources of power, there are some environmental impacts associated with the construction, operation and decommissioning of the infrastructure – the turbines and their towers and foundations, the offshore substations, and the associated submarine power cables that connect to onshore electricity substations and grids. While the precise environmental footprint of an offshore wind farm will depend on its location in relation to threatened habitats, bird migration routes, and other natural features, there are several potential impacts on biodiversity.

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The sensitivity of yellow-legged gulls (*Larus michahellis*) to collision or displacement risk from offshore wind farms is unknown and needs to be studied further, according to BirdLife International (2021).

While there is still much to understand about many of the pressures placed on nature by OWE, Bennun et al. (2021) identify fourteen potential environmental impacts. Particular attention has been paid to the potential for birds and bats to collide with the turbines. Although collision rates are hard to determine at sea and data are sparse (Thaxter et al., 2017), some studies have produced estimates for bird collisions, ranging from one collision per turbine per year (Petersen et al., 2006) to 16.5 to 21.5 collisions per turbine per year (Newton & Little, 2009), with some taxa more susceptible than others (King, 2019). There are also concerns about, for example, habitat loss and degradation (under the foundations or caused by sediment plumes) as well as hydrodynamic changes caused by construction, and the effects on wildlife of pollution and noise from construction activities and operations, collisions with construction and maintenance vessels, and electromagnetic fields generated by submarine power cables (OSPAR Commission, 2008b; Boehlert & Gill, 2010; Bergström et al., 2014; Lüdeke, 2018; Taormina et al., 2018; Perrow, 2019; Copping et al., 2020; Bennun et al., 2021). In addition, if mitigation measures are not taken, invasive alien species (IAS) may be introduced to offshore wind farms by construction and maintenance vessels and equipment, and the hard substrates provided by foundations can allow newly introduced species to become established or existing IAS populations to expand (Wilhelmsson & Malm, 2008; De Mesel et al, 2015; Geburzi & McCarthy, 2018; Iacarella et al., 2019; Coolen et al., 2020). In particular, OWE infrastructure can operate as stepping zones promoting the colonisation of hard-substratum species with pelagic larvae (Perrow, 2019).

Multiple offshore wind farms and their associated grids can lead to cumulative impacts on biodiversity, multiplying effects as well as compounding other anthropogenic pressures (King et al., 2015; Nogues et al., 2021). Bennun et al. (2021) note that the biodiversity most at risk from the pressures from OWE include birds (seabirds, migratory shorebirds and waterfowl), bats, marine mammals, marine turtles and fish, as well as a variety of offshore and coastal habitat types, such as sandbanks, coral reefs, seagrasses, mangroves, salt marshes, oyster beds and wetlands.

The location, design and type of technology used in an offshore wind farm and its associated grid infrastructure affects the impacts on biodiversity. For example, floating turbines will have less of a footprint on the seabed than bottom-fixed turbines, although mooring cables (especially nylon-containing catenary moorings) may increase the risks of marine mammal entanglement (Benjamins et al., 2014; Bennun et al., 2021). Meshed grids require less power cable than radial grids (Cole et al., 2014) and so are expected to have less environmental impact. Construction of gravity foundations does not involve pile driving like monopiles or jacket foundations and so is significantly less noisy (Hammar et al., 2008). On the other hand, gravity foundations involve higher impact from sediment dispersal due to dredging (Bergström et al., 2014). However, of the five types of offshore wind turbine structures currently in use (monopiles, gravity-based foundations, jacket, tripod and floating structures), the exact influence of the structure type on the degree to which species are attracted or repelled has not yet been quantified (Degraer et al., 2020).

While there are diverse pressures and impacts that can be placed on the marine environment during construction, operations and decommissioning of offshore wind farms, a wide range of mitigation measures have been developed that can reduce those impacts (see section 5.3).

3.2.2 Potential enhancement of biodiversity

Certain species can thrive around OWE installations and grids and, where any organisms increase rather than decrease in abundance, this is often termed a ‘positive impact’. Offshore wind energy infrastructure, especially foundations, can act as artificial reefs or fish aggregation devices, introducing new hard substrate habitat in soft-bottomed seas (e.g., Wilhelmsson et al., 2006; Inger et al., 2009; Stenberg et al., 2015; Perrow, 2019; Degraer et al., 2020; Coolen et al., 2022). Underwater OWE structures and submarine power cables are usually colonised by hard-substrate benthic species including epifauna (e.g., bivalve molluscs, corals) and mobile macrofauna (e.g., worms, crustaceans). This reef effect can attract megafauna, such as decapod crustaceans and fishes (Reubens et al., 2014; Degraer et al., 2021) and a sessile macrofauna community rapidly colonises the new hard substrates created by OWE infrastructure, usually within a few months (Gutow et al., 2014). In turn, the exclusion of human activity, especially fishing, can lead to a reserve effect and further encourage aggregations of marine organisms (e.g., Bergström et al., 2013; Hammar et al., 2016). Some studies suggest that, in general, fish abundance is elevated inside offshore wind farms (Methratta & Dardick, 2019).

As well as the aggregations of marine organisms around offshore wind farms caused by the reef effect and reserve effect, additional efforts to enhance the habitats for native species, including nature-inclusive design and targeted restoration efforts can further encourage biodiversity in offshore wind farms. For example, nature-friendly scour protection or artificial habitats can increase the abundance of taxa such as fish, crabs, oysters and lobsters (Glarou et al., 2020; The Rich North Sea, 2023; Wageningen University & Research, 2023). See section 5.3 for more detailed descriptions of proactive conservation actions around OWE.

Although the diversity and abundance of certain species increases around offshore wind farms, this is the case for most human-made structures placed in the sea (see, e.g., Coolen & Jak, 2018); even plastic waste floating in the ocean provides new habitats for many coastal species (Haram et al., 2023). But artificial habitats alter species communities: the diversity and abundance of some taxa increase but other taxa decline, and the altered species assemblages no longer form a natural ecosystem. The macrofauna community around OWE is “impoverished relative to that expected on natural hard substrata in similar oceanographic conditions, with dominance of a few species”, such as tube-building amphipods, anemones, hydroids, blue mussels and shrimps (Perrow, 2019). Similarly, fish aggregations around OWE are usually composed of species assemblages that differ from those in surrounding natural habitats (Bergström et al., 2013; Ashley et al., 2018; Degraer et al., 2020).

A review of 31 studies found a change in species assemblages at offshore infrastructure in comparison to naturally occurring habitats, with an increase in hard substrata associated species, especially benthic bivalves, crustaceans and reef associated fish, and a decrease in algae abundance, being the dominant trends (Ashley et al., 2018). The impacts witnessed on demersal fish close to offshore wind farm foundations include increased densities of piscivore species (cod, eel, shorthorn sculpin) and the reef-associated goldsinny wrasse, and an absence or reduction in their prey species (black goby, eelpout and shore crab) (Bergström et al., 2013). Flatfish have also been recorded at lower abundance near monopiles than in surrounding sandy bottomed habitats (van Hal et al., 2012). Fish communities around wind farms in the Baltic Sea were different to the surrounding seabed, with total fish abundance higher but species richness and diversity lower (Wilhelmsson et al., 2006). Species close to offshore wind farm foundations tend to be ones that favour rocky, hard substrate environments rather than sedimentary environments (Stenberg et al., 2015). The benthos is also different, with climax communities around offshore wind farms dominated by mussels and anemones (Degraer et al., 2020).

Overall, therefore, although offshore wind farms may cause a reef effect and an increase in the biomass of fish, crustaceans and benthic species, “the naturally occurring community has been altered” (Ashley et al., 2014), a situation found across European sea basins (Wilhelmsson et al., 2006; Bergström et al., 2013; Stenberg et al., 2015; Ashley et al., 2018; Degraer et al., 2020). Since the species assemblages occurring on OWE structures are different from surrounding habitats, and likely to remain different indefinitely, they will not be helping conserve natural ecosystems. Furthermore, as discussed above, IAS may be attracted to the infrastructure and become an integral part of the new species community, competing with and threatening native species and further altering the natural species assemblages. The change in species assemblages is not restricted to species underwater. Monitoring around the Horn Rev offshore wind farm in Denmark showed changes in seabird communities using the area, with species like gannet, common scoter and common guillemot less abundant than expected (Petersen et al., 2004) but gulls, terns and cormorants more numerous than expected (Kahlert et al., 2004).

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Around some offshore wind farms, great cormorants (*Phalacrocorax carbo*) have been recorded in higher densities than before construction. The species is considered by BirdLife International (2021) to have a moderate risk of collision with offshore wind turbines.

3.2.3 Potential impacts on MPAs

Most published studies on OWE impacts on nature were conducted outside of MPAs, and this review did not uncover any research into the relationship between MPA goals and colocated OWE. However, the potential effects of colocation can be extrapolated from known environmental impacts identified outside of MPAs, as well as a handful of case studies within MPAs.

Although some birds are attracted to offshore wind farms by the aggregations of fish or (in the case of cormorants and shags) to roost or dry their wings on the infrastructure, OWE can threaten birds at an individual level (Dierschke et al., 2016) and a population level (Thaxter et al., 2015; Masden & Cook, 2016), so offshore wind farms are unlikely to help seabird conservation (Hammar et al., 2016). Therefore, any MPAs protecting birds, such as SPAs under the Birds Directive, are likely to struggle in delivering their conservation goals if colocated with offshore wind farms. Even though colocating wind farms with MPAs is legally feasible in the UK under certain conditions, permission for a wind farm in the North Norfolk Coast SPA was refused because of the threats it posed to foraging Sandwich terns, one of the target bird species of the MPA (Christie et al., 2014). Similarly, two offshore wind farm proposals in the North Sea (one for 101 turbines off the coast of Callantsoog and another for 137 turbines near Zuid-Holland) were rejected by Dutch courts due to concerns for the impacts on a protected bird species, the great black-backed gull (Sanders et al., 2017).

Marine mammals (pinnipeds and cetaceans) are mostly impacted in the construction phase. The European Maritime Spatial Planning Platform (EC, 2023f,g) notes that “conflicts between offshore wind farming and area-based marine conservation mostly arise on account of noise disturbance and displacement”. Although marine mammal activity can return to normal when construction is complete (Hammar et al., 2016), in some sites long-term impacts last for several years (Teilmann & Carstensen, 2012). Construction impacts are expected to be higher in pristine areas compared to areas where ambient noise is already high (Scheidat et al 2011; Bergstrom et al., 2014). This suggests that construction in areas with low ambient noise, such as would be expected in well-managed MPAs, may have a disproportionately negative impact on marine mammals (Sanders et al., 2017).

For MPAs conserving benthic assemblages of fish, crustaceans and other organisms, natural habitats or geological features, the impacts of OWE will depend on the sensitivity of the species, habitats or features and the estimated significance. However, given the species assemblages occurring on OWE structures are different from surrounding habitats, and likely to remain different indefinitely (see above), MPAs conserving natural ecosystems will be challenged by OWE. If Europe is to achieve its stated biodiversity goals it needs to focus efforts on protected areas “of very high biodiversity value or potential” (EU, 2020). If it is to contribute to global ambitions, it also needs to ensure European protected areas networks, including MPA networks, are ecologically representative and conserve areas of particular importance for biodiversity and ecosystem functions and services (CBD, 2022). In light of such ambitions, the alteration of naturally occurring species communities around offshore wind farms are unlikely to help deliver the goals of the European MPA network.

Invasive alien species are one of the biggest global threats to biodiversity (IPBES, 2019; UNEP, 2019). MPAs are expected to provide protection from IAS, with significantly lower IAS richness predicted from available data (Gallardo et al., 2017). Another study concluded that, although more data are needed on various taxonomic groups across different biogeographic regions, generally “alien species respond negatively to protection” and the density of most alien species was found to be greater outside MPAs than inside (Giakoumi & Pey, 2017). Since, as described above, the support vessels and the hard substrate foundations of offshore wind farms can attract IAS, colocating offshore wind farm in MPAs is likely to compromise the ability of MPAs to protect against IAS, as will other human activities. However, the relative threat from offshore wind farms of introducing IAS or providing stepping stones for their dispersal needs to be taken in the context of the broader array of artificial structures in the sea (see section 3.2.5) and the need for more robust knowledge of the mechanisms of IAS dispersal (Dannheim et al., 2020).

3.2.4 Case studies of offshore wind farms in MPAs

A handful of case studies of offshore wind farms colocating with MPAs was identified (Table 1), although available data on the environmental consequences were inadequate to draw significant conclusions. The problem of knowledge gaps is also noted by government agencies involved; for example, the UK's Joint Nature Conservation Committee notes that, for the Outer Thames Estuary, there are no long-term condition monitoring data available "to determine whether the SPA is moving towards or has reached its conservation objectives" (JNCC, 2023a), and for Liverpool Bay no information is available to assess progress towards conservation objectives (JNCC, 2023b). The management plan for the German SPA Östliche Deutsche Bucht (BfN, 2020) notes that OWE can compromise the habitat connectivity important for the reefs in the MPA, but no data were uncovered to confirm if this connectivity has been maintained or not. This general lack of data from government agencies or the scientific literature may be due partly to the fact that many projects are relatively new, and partly due to inadequate data collection and data sharing.

Of the limited data available on OWE effects on MPAs, a key one was that offshore wind farms in England displaced red-throated divers (a Birds Directive Annex 1 species) from two MPAs (Liverpool Bay SPA and Outer Thames Estuary SPA), with no evidence divers ever habituated to offshore wind farms and returned to pre-construction densities (Allen et al., 2020). Given the red-throated diver was a qualifying species for both SPAs (and in Liverpool Bay additional seabird species are targeted for conservation; JNCC; 2023b), the colocated offshore wind farms must pose a significant threat to the birds and the MPAs' objectives. The avoidance of OWE by red-throated divers was also observed in Denmark, where divers were not recorded closer than 1,400 m from turbines (Kahlert et al., 2004), and in Germany, where divers were at lower-than-normal densities for more than 10 km from offshore wind farms (Heinänen et al., 2020; Vilela et al., 2020; Garthe et al., 2023). This underlines the fact that red-throated divers are one of the 19 seabird species most at risk of collision or displacement by OWE (BirdLife International, 2021) and one of the taxa most at risk from population-level impacts (Furness et al., 2013).

Harbour seals near the Scroby Sands offshore wind farm declined during the year of construction, and had not fully recovered by the end of the monitoring period reported (Nehls et al., 2019). The cause was reasoned to be the piling noise, although grey seals in the area increased annually, in spite of the construction (although short-term disturbance and displacement could not be discounted). Elsewhere, harbour seals have been displaced more than 25 km by piling (Russell et al., 2016).

Where negative impacts may be less significant in affecting conservation goals is when the target taxa are not birds or mammals. It is notable that most of the offshore wind farms that have been approved in British conservation sites and for which data were found are in MPAs with a focus on features such as subtidal mud and sand habitats, sea-pen and burrowing megafauna communities, and polychaete worm reefs (*Sabellaria spinulosa)* (Ashley et al., 2018). In these cases, the expected impact of the wind farm was determined by EIAs to be insignificant (less than 1% of the area of the target features). However, there is still a risk to conservation goals. For example, in the West of Walney Marine Conservation Zone, the goal of the MPA is for protected features such as sea pens to recover (Ashley et al., 2018). However, the loss of even small areas of these features could retard the recovery to a 'favourable' condition (Mazik and Smyth, 2013), thereby jeopardising the goal of the MPA. Some reports and monitoring data were found for the site on Marine Data Exchange (The Crown Estate, 2023) but no evidence was found to allow an assessment of whether or not the sea pens or reefs are recovering.

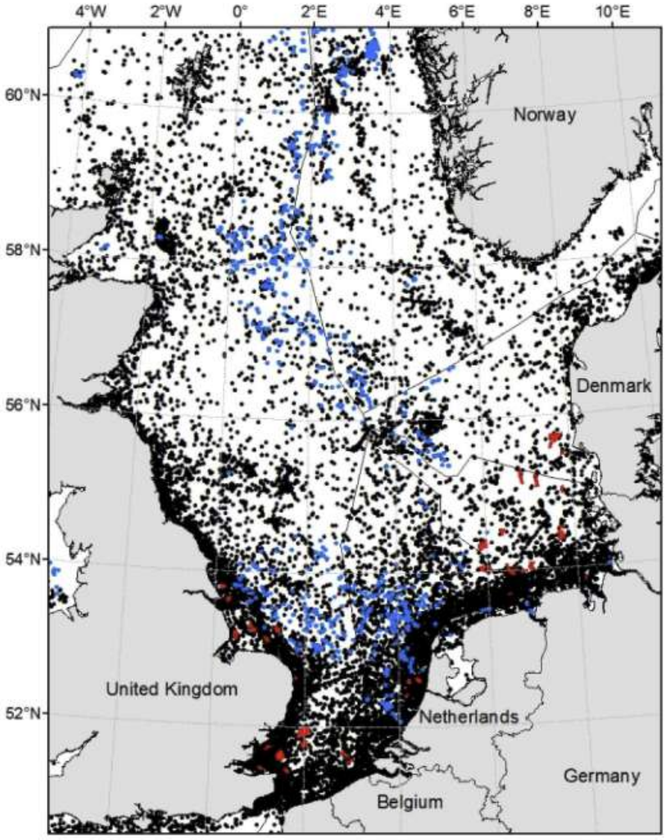
Table 1. A selection of case studies presented in the literature on the colocation of offshore wind farms with MPAs. IUCN management categories were reported only for the Firth of Forth SPA and Forth Islands SPA (which are category IV), the SPA Östliche Deutsche Bucht (Category IV) and Golfe du Lion (Category V) (UNEP-WCMC, 2023). Note that, in addition to colocation with wind farms, several cable connections and service vessels traverse MPAs (Defingou et al., 2019).

Country	Offshore Wind Farms	MPAs	Notes	Source
England	Walney, West of Dudden & Ormonde	West of Walney Marine Conservation Zone	Key features: Subtidal sand and subtidal mud; Sea pen and burrowing fauna communities. Helped "limit the total area that might otherwise be closed to fishing"; impact was in small % of MPA	Ashley et al., 2018
England	Lincs, Lynn and Inner Dowsing, Race Bank and Triton Knoll	Inner Dowsing, Race Bank and North Ridge Site of Community Importance	Key features: sandbanks; *Sabellaria spinulosa* (polychaete worm) reefs. Impact was in small % of MPA	Ashley et al., 2018; Defingou et al., 2019
England	North Hoyle, Burbo Bank, Rhyls Flats, Gwynt y Môr	Liverpool Bay SPA	Both SPAs used red-throated divers as qualifying features; for Outer Thames Estuary the species was the sole feature as it supports 38% of the British population; for Liverpool, Bay, other seabird species are features. The offshore wind farms displaced red-throated divers which did not recover to pre-construction densities. Benthic communities in North Hoyle were not back to normal after 12 months. Harbour seals declined in Scroby Sands during construction and did not recover fully.	Allen et al., 2020; JNCC, 2023b
England	Scroby Sands, Kentish Flats 1 & 2, Gunfleet Sands 1 & 2, London Array 1	Outer Thames Estuary SPA		Allen et al., 2020; Percival, 2014; Nehls et al., 2019
France	Golfe du Lion (expected end of 2023)	Parc Naturel Marin Golfe du Lion	More than 1200 animal species and 500 plant species found in the MPA, including 8 of the 10 marine species protected nationally; the board of the park created a working group to ensure impacts were minimised but the effectiveness will only be measurable when the wind farm is completed	Defingou et al., 2019; WWF-France, 2019; Révolution Energétique, 2022; OFB, 2023
Germany	Butendiek	SPA Östliche Deutsche Bucht	Protects 19 species (14 birds, 2 fish and 3 mammals – grey and common seal and common porpoise) listed in Nature Directives and 2 habitat types (sandbanks and reefs) under the Habitats Directive.	Defingou et al., 2019; EEA, 2019; Butendiek, 2023
Scotland	Neart na Gaoithe, Inch Cape, Seagreen Alpha and Bravo	Firth of Forth Ramsar site, Firth of Forth SPA, Forth Islands SPA, Firth of Tay and Eden Estuary SPA	The opposition to the consent was based on the potential impacts on bird species of concern (e.g., kittiwake, gannet, puffin) associated with the SPAs but this was ultimately rejected; additional wind farms are planned for the area	EC, 2023g (MSP Platform Conflict Fiche 8); RSPB

3.2.5 The environmental impacts of offshore wind energy in perspective

There are numerous and widespread human pressures on marine ecosystems in Europe (Korpinen et al., 2021). The data available on relative and cumulative impacts suggest that OWE is likely to have lower levels of anthropogenic impacts on many species and habitats than other maritime activities, such as fishing, dredging, shipping, oil and gas exploitation and recreation (Mazaris et al., 2019; Hammar et al., 2020; Starmore et al., 2020). For example, one review found recreational activities and fishing to be the main threats affecting European MPAs (Mazaris et al., 2019). Globally, fishing has had the largest relative impact on marine ecosystems (IPBES, 2019). Furthermore, the environmental impacts of OWE are discrete in space and time, whereas the impacts of certain fishing techniques such as bottom trawling can be much longer lasting and devastating (Inger et al., 2009; Sanders et al., 2017). Compared to other industries, the construction and operation of offshore wind farms is relatively well studied and lessons learned in Europe show that efficient mitigation measures "have been highly successful in reducing adverse effects on marine wildlife" (WWF-France, 2019).

Figure 1. Locations of wrecks (black dots), oil and gas installations (blue dots) and wind farms (red dots) in the North Sea. Reproduced with permission from Coolen & Jak (2018).



The threat from alien invasive species is a good example of the relative impact of OWE. As explained above, OWE infrastructure provides hard substrate habitats that are colonised by many species, including IAS. Coolen & Jak (2018) noted that, while many hard substrate habitats like oyster reefs have declined in the North Sea in the last century, human-made hard substrates have increased. This not only includes offshore wind turbines, foundations and associated grids but also ship wrecks and oil and gas installations (which, as they exploit fossil fuels, obviously have additional environmental impacts). All of these structures attract similar species assemblages (Zintzen et al., 2006; Bouma & Lengkeek, 2013; van der Stap et al., 2016). However, as demonstrated by Figure 1, there are fewer artificial hard substrate habitats created by OWE than by other shipwrecks or oil and gas installations (Coolen & Jak, 2018). While these data are now a few years old, they demonstrate that the pressure of IAS on marine ecosystems caused by OWE, especially in the heavily exploited North Sea, is likely to be less significant than that caused by other types of structures, at least in the near future. Of course, any threat to the marine environment in the North Sea and elsewhere needs to be avoided, especially in areas of conservation importance such as MPAs, and being less of a threat than other causes does not provide justification for placing infrastructure in MPAs. But this study does suggest that OWE sited to avoid sensitive areas may add a relatively small increment to the artificial substrates present in this sea basin.

As discussed in section 3.2.1, the location, design and type of technology used in an offshore wind farm and its associated grid infrastructure will also affect the impacts on biodiversity. In addition, many of the environmental issues around OWE are specific to the site, species or sea basin concerned. The significance of any effect of OWE on nature will “vary depending on factors such as magnitude of effects, type, extent, duration, intensity, timing, probability, cumulative effects and the vulnerability of the habitats and species concerned” (EU, 2020). For example, the sensitivity of bird species to displacement or turbine collisions varies between species (BirdLife International, 2021); in some sites marine mammals have returned after construction of wind farms (Hammar et al., 2016), in others they have stayed away (Teilmann & Carstensen, 2012). While corals and seagrasses can take a long time to recover from disturbance (Gouezo et al., 2019; Morris et al., 2022), the microbenthic community in low species abundance/low density soft substrates like sandbanks can recover relatively quickly and without the loss of rare species (Coates et al., 2015; Li et al., 2023).

Sea basins are also different; compare the North Sea with the Mediterranean. In the North Sea, such as on the Dutch continental shelf, coastal waters have been heavily exploited and ecosystems degraded since the mid-1990s (Lindeboom, 1995). In such cases, if offshore wind is sited away from important biodiversity sites, the benefits caused through the reef effect may outweigh any negative effects, especially if complemented by nature-inclusive design and restoration activities. On the other hand, OWE developments are more likely to cause significant negative impacts to the more diverse, heterogeneous and threatened habitats of the Mediterranean. The Mediterranean has the highest proportion of threatened marine habitats (32%) in Europe (Gubbay et al., 2016). The particular complexity and fragility of Mediterranean habitats mean that, for example, any ecological benefits related to an increase of habitat heterogeneity linked to offshore wind farms, as described for northern European seas, would be absent in the Mediterranean, given it already has high habitat heterogeneity (Lloret et al., 2022). On the other hand, all the adverse effects described in the northern European seas could be magnified in the semi-closed Mediterranean with such high biodiversity and endemism (Lloret et al., 2022).

The variation in environmental impacts of OWE, and the relative impacts when compared with other threats, will need to be factored into MSP processes.

3.3 Current Status of Marine Protected Areas

The current outlook for MPAs in Europe is bleak.

3.3.1 MPA management plans

MPAs need comprehensive management plans that address all cumulative human stressors which impact biodiversity if they are to provide effective protection for species and habitats. However, a review found that 19 of the 23 marine EU Member States have no management plans, or hardly any management plans, in place for their MPAs (WWF EPO, 2019). This means that only 1.8% of the EU marine area is covered by MPAs with management plans, despite 12.4% of the EU marine area being designated for protection (WWF EPO, 2019). The European Environment Agency (EEA) notes that “EU Member State authorities and stakeholders could do more to meet the standards set out in EU guidance on management planning, such as setting conservation objectives and establishing conservation measures” (EEA, 2023). In addition to hampering effective conservation, the absence of management plans and defined management goals for many MPAs further complicates discussions on colocation with other maritime activities. For example, national policies in countries such as Belgium, France and the UK allow for offshore wind farms to be colocated with MPAs if conservation objectives are not affected significantly. This review was not able to identify any MPAs that explicitly focus on any marine life not affected in any way by OWE. However, since MPA plans are rare in Europe, it is not easy to assess how many European MPAs may have conservation goals compatible with OWE. The use of IUCN management categories is also rather ad hoc, meaning that, for many MPAs, the level of protection afforded to them, or the level of sustainable use permitted, is unclear. For example, only four of the ten MPAs in the case studies shown in Table 1 had a confirmed IUCN category assigned to them. Defining MPA objectives and management categories, and developing management plans, is therefore a priority for helping define more clearly what human activities should be allowed and what they might impact.

3.3.2 Effectiveness of MPAs

The density, biomass, body size and diversity of most marine life has been shown to be greater inside MPAs than outside (Halpern, 2003). For example, effective MPAs have been found to provide refuges for fish, housing twice as many large fish species, five times more large fish biomass, and fourteen times more shark biomass than fished areas (Edgar et al., 2014). There are several factors influencing the effectiveness of MPAs in conserving biodiversity. One global review found that staff and budget capacity were the strongest predictors of conservation impact: MPAs with adequate staff capacity had ecological effects 2.9 times greater than MPAs with inadequate capacity (Gill et al., 2017). In another global review of 87 MPAs, Edgar et al. (2014) found that conservation benefits increase exponentially with the accumulation of five key features: no offtake, good enforcement, old age (more than 10 years) large size (more than 100 km^2), and isolated by deep water or sand. Many European MPAs fail to meet these criteria. The majority of European MPAs are designed to be partially protected MPAs, which are divided into zones allowing extractive activities to occur to differing degrees, often including bottom-trawling (WWF EPO, 2019, 2022a).

Approximately 89% of the marine Natura 2000 area and 85% of the national designated sites area are found within sites that are less than 100 km^2 (EEA, 2015b). It is not possible to quantitatively assess whether EU MPAs are no-take areas or not, as no harmonised, easily accessible data are available (EEA, 2015a)[6]. However, in 2012, it was estimated that 74 no-take reserves existed in the waters of 16 European countries, covering less than 1,000 km^2 in total, or less than 0.5% of the area covered by the European MPAs (Fenberg et al., 2012). This suggests the ambition to attain 10% strict protection (EC, 2020a) is not likely to be met.

“Governments have markedly underinvested in protected areas and OECMs and been weak in legally protecting them” (Maxwell et al., 2020). Although it is not possible to assess the level of enforcement quantitatively due to lack of data (EEA, 2015a), there is a lot of evidence of weak protection. Many MPAs are ‘paper parks’, with limited enforcement of the controls on exploitation activities that are necessary to meet conservation objectives (EEA, 2015a). For example, in general, “Natura 2000 sites are not closed for commercial fisheries, or only partly so” (EEA, 2015a). A study in Sweden found only 3 out of 56 MPAs (5%) prohibited fishing (Grip & Blomqvist, 2020). Across the UK, MPAs are generally considered multi-use sites and there is very little active management or enforcement of regulations and controls (Clark et al., 2017; Solandt, 2018).

The lack of protection comes in spite of the public in many European countries, including Estonia, the Netherlands, Norway and the UK, valuing and supporting offshore nature conservation and MPAs (e.g., Börger et al., 2014; Aanesen et al., 2015; Brouwer et al., 2016; Karlõševa et al., 2016). The EEA notes that “existing management effectiveness standards are insufficiently known and understood among practitioners” and “Member States could better use EU funding to fill the investment gap on Natura 2000 management effectiveness by setting out prioritised action frameworks” (EEA, 2023).

3.3.3 Integrating MPAs into maritime spatial planning

Although maritime spatial planning should include all uses of the ocean, in reality, “MSP and MPA designation are often taking place in parallel to each other, with relatively little integration between

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[6] The Protected Seas Navigator database on MPAs and their regulations (https://protectedseas.net/mpa-mapping) and the Marine Protection Atlas (https://mpatlas.org/) now provide a potential means of conducting a new analysis in the future.

them”, as seen in European countries like Germany and the UK (Trouillet & Jay, 2021). Uncoordinated planning of wind farms and MPAs in Belgium, exacerbated by inadequate stakeholder engagement, caused significant problems and led to the degazettement of the MPA (Pecceu et al., 2016). The obvious risk is that a lack of integrated MSP will lead to MPAs being designated in sites already allocated for wind farm development, resulting in inadvertent colocation, or more MPAs being declassified due to OWE developments.

The EU Maritime Spatial Planning Directive states that “maritime spatial planning should apply an ecosystem-based approach” (EU, 2014), which has been defined by the CBD as “a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way” (CBD SBSTTA, 2000). The United Nations, the Organisation for Economic Co-operation and Development, and the Baltic Marine Environment Protection Commission (HELCOM) have also all dedicated special efforts to engage and further operationalise the ecosystem-based approach (Stephenson, 2022). However, a review of 12 European case studies demonstrated that the approach is inadequately implemented (Domínguez-Tejo et al., 2016), a finding supported by a recent BirdLife International review of marine spatial plans in four countries (BirdLife International, 2022). Relevant features of the ecosystem-based approach rarely applied include the standardisation of pressures from human activities, the integration of frameworks to assess ecosystem services, and the implementation of precautionary and adaptive management approaches (Domínguez-Tejo et al., 2016). Important knowledge gaps were also highlighted, especially in relation to the assessment of social values and social connections to the marine environment.

Since nature continues to decline, there is a risk we continue to set conservation ambitions against already reduced levels and inappropriate baselines (Papworth et al., 2009; Soga & Gaston, 2018), a phenomenon called shifting baseline syndrome (Pauly, 1995). Therefore, in planning for conservation and sustainable use of the oceans, governments need to ensure that they maintain the level of ambition laid out in the EU Biodiversity Strategy and in line with the Kunming-Montreal Global Biodiversity Framework.

3.4 Mitigating Impacts When Offshore Winds Farms Are Colocated With MPAs

Given that some countries, such as Belgium, France, Germany, Greece and the UK, allow colocation of OWE and MPAs in at least some circumstances, and given the disconnect between MPA designation and broader MSP processes, it is inevitable that some offshore wind farms will continue to be colocated in MPAs and OECMs. As discussed, this review found inadequate data on the impacts of offshore wind farms already colocated within MPAs. However, what we already know about potential environmental impacts and mitigation measures needs to inform the approaches to be taken when colocation occurs.

Traditionally, companies across sectors have used the Mitigation Hierarchy as a tool to help limit their negative impacts on biodiversity by considering four actions (avoid, minimise, restore, offset) in setting no-net-loss or net-gain targets (Ekstrom et al., 2015). According to a review across seven European countries, many EIA reports conclude that positive impacts of OWE are greater than negative impacts and “there should be no significant negative residual impacts and hence no need of offsets” (Vaissière et al., 2014). However, residual impacts can be difficult to predict, particularly before but also during early project construction and operations, especially in data-poor regions and many offshore environments (Bennun et al., 2021). As a result, the Mitigation Hierarchy and the use of offsets are often inadequate in the OWE sector, with some offsets proposed onshore for offshore impacts, raising issues of equivalency (Vaissière et al., 2014). Given that restoration and offsetting are often complex, costly, small-scale, difficult to measure and with unpredictable success rates (Bennun et al., 2021; Stephenson & Walls, 2022), as the OWE sector considers colocation and enhancing nature, more emphasis should be placed on the avoid and minimise steps and, in such instances where OWE is colocated with MPAs, mitigation measures will need to be maximised and applied thoroughly.

According to IUCN guidelines (Bennun et al., 2021), key avoidance and minimisation measures for the construction and operation phases include the implementation of physical controls (modifying the physical design of project infrastructure to reduce operation-related impacts, such as bird collisions), operational controls (involving managing and regulating contractor activity and movement during construction and maintenance) and abatement controls (involving taking action to reduce, for example, emissions, noise and pollutants). Similar controls will be required during the repowering[7] or decommissioning phase of a wind farm. It will be essential throughout to select construction methods and implement construction protocols that reduce environmental impacts, especially for sensitive species and for the species and habitats that are the focus of the MPA's objectives. It is also recommended that offshore seabed disturbance should be restricted to the minimum area required for installation of a foundation, or for cable laying. OWE developments, particularly where components are located in degraded coastal or sea areas such as heavily-trawled areas, are also encouraged to take further steps to enhance the habitat on site to create benefits for biodiversity (Bennun et al., 2021)

In such cases of colocation, however, even with mitigation and restoration measures, some degree of disturbance to the MPA ecosystem is inevitable; at the very least, species assemblages are likely to differ from the natural, undisturbed state and the most sensitive species will be displaced (see section 3.2).

3.5 Knowledge Gaps

Several pressures and impacts of OWE on biodiversity remain poorly understood, as do some strategies to mitigate and monitor impacts. Also, most current publications are derived from studies conducted at localised scales, such as in shallow waters, close to the coast, with few turbines, low production capacity, and occupying a small area (Galparsoro et al., 2022). More data are needed on the impacts of larger wind farms in deeper waters further offshore.

A range of studies and reports (e.g., Bergström et al., 2014; Copping et al., 2020; Taormina et al., 2018; Abhinav et al., 2020; Dannheim et al., 2020; BirdLife International, 2021; Stephenson, 2021; Watson et al., 2023) have identified a diverse set of priorities for further research to fill our knowledge gaps, including (but not limited to):

- the collision risk of bats offshore;
- the entanglement risk of marine mammals and bird with mooring lines and cables;
- the adverse effects of OWE and submarine power cables on marine turtles;
- understanding how prey distribution and density affects marine mammal use of OWE sites;
- the impacts on marine organisms of electromagnetic fields (especially from submarine power cables), including data on sensitivity thresholds and tolerance for a larger number of taxa;
- the barrier effects on birds and the use and effectiveness of corridors created within and between wind farms
- levels and impacts of pollution such as oil spills from vessels involved in construction, maintenance and decommissioning of OWE;
- hydrodynamic changes possibly resulting in altered primary production and potential consequences for filter feeders;
- the introduction and range expansion of IAS (through stepping stone effects);
- noise and vibration effects on benthic organisms;
- cumulative impacts and long-term effects on the food web;
- combined effects with other human activities, such as fisheries;
- the most nature-positive way of decommissioning OWE infrastructure (including assessment of the impacts of contaminants impacts, defining risk and acceptability thresholds in policy

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[7] Repowering is replacing units with newer, higher capacity turbines or retrofitting them with more efficient components.

and governance and quantification of impacts to ecosystem services) and if, and how best, to restore sites;

- the potential for new techniques to be integrated into OWE monitoring systems, especially environmental DNA techniques for assessing species diversity and relative abundance, baited remote underwater video for fish and possibly crustaceans, light traps for benthic invertebrates, acoustic soundscapes for fish and crustaceans, and the systematic monitoring of ship hulls for invasive alien species
- the factors affecting the success of impact mitigation measures and restoration opportunities
- the technical and economic viability of different colocation scenarios and multi-use systems involving OWE, including comparative assessments of diverse economic activities.

If we are to understand fully the environmental repercussions of continued expansion of OWE, and the best means of mitigating impacts, these gaps need to be filled. As well as targeted research, monitoring needs to be improved in and around offshore wind farms (see Stephenson, 2021 for review, and section 5.4).

This review found only a small number of concrete examples (Table 1) in the literature of OWE/MPA colocation. Case studies that do exist do not provide adequate data or consistent results to draw conclusions from. Many of the offshore wind farms built within MPAs are relatively recent developments so data are not yet long-term, but more data should be available. Certain assumptions were made when the developments were approved about the insignificant impact expected on species and habitats. Data from the monitoring of these wind farms need to be collected and shared to provide stronger evidence of the impacts and of the validity of the assumptions made in their approval.

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Sea ducks such as common eider (*Somateria mollissima)* are considered to be at high risk from OWE developments and are a priority for further research (BirdLife International, 2021).

The Precautionary Principle (sometimes known as the Precautionary Approach) has been adopted by the CBD (2010) and is already enshrined in EU policy in the Habitats Directive (EC, 1992), the EU Marine Strategy Framework (EU, 2008), and the EU Maritime Spatial Planning Framework (EU, 2014). The approach has also been adopted in principle by several European countries (e.g., DECC, 2016). For OWE, RGI (2019) and its partners have noted that “marine spatial planning for grid activities shall be based on best available science and mapping data, and a precautionary approach where data is missing”. However, there is evidence the Precautionary Principle is not being applied consistently in European marine spatial planning (Domínguez-Tejo et al., 2016). The sooner the full impacts and cumulative impacts of OWE can be understood, the more decisions can be taken based on data, reducing reliance on the Precautionary Principle (Stephenson, 2022).

4. Offshore Wind Energy and Other Maritime Activities

In addition to renewable energy production and the conservation of species and habitats, the EU Maritime Spatial Planning Framework (EU, 2014) identifies several other activities and uses to consider in marine areas, including: aquaculture areas; fishing areas; installations and infrastructures for the exploration, exploitation and extraction of oil, gas, minerals and aggregates; raw material extraction areas; maritime transport routes and traffic flows; military training areas; scientific research; submarine cable and pipeline routes; tourism; and underwater cultural heritage.

European seas are heavily exploited. The EU is the sixth-largest producer of fishery and aquaculture products, and nearly 80% of global shipping (by volume) and over 90% of installed offshore wind capacity occurs in EU seas (EC Directorate-General for Maritime Affairs and Fisheries, 2022). With such high shipping densities and vast fishing operations, it is increasingly important for Member States and their neighbours to incentivise the colocation of human activities. The idea that space can only be occupied by a single activity in a given area has contributed to EU delays in delivering on its nature conservation commitments, as this approach leaves little room to expand MPAs and areas for renewable energy production (WWF EPO, 2022c).

The EU Strategy to Harness the Potential of Offshore Renewable Energy (EC, 2020b) encourages the coexistence of renewable energy with activities such as fisheries, aquaculture, shipping and tourism, especially “in crowded areas”. While ultimately, a more detailed review of the relationship between OWE and each of these activities is required, below is a summary of some of the key issues.

4.1 Colocating Offshore Wind Energy with Fisheries and Aquaculture

4.1.1 Fisheries

Several species of fish and crustacean of importance to European fisheries (e.g., Atlantic cod, pollock, brown crab, European lobster) have been recorded in increased densities around offshore wind farms (Langhamer & Wilhelmsson, 2009; Bergström et al., 2013; Ashley et al., 2014; Hooper & Austen, 2014; Hooper et al., 2018; Perrow, 2019). The EU Biodiversity Strategy (EC, 2020a) highlights the fact that offshore wind “allows for fish stock regeneration” which implicitly encourages the use of offshore wind farms as areas for conserving fisheries. However, in most European countries, active fishing is prohibited in offshore wind farms (EC, 2023h). This is largely due to the practical safety issues around operating boats and fishing gear among turbines, and the need to protect the foundations and submarine power cables. This has caused concerns about the fisheries lost to offshore wind farms. For example, in the German Exclusive Economic Zone of the North Sea, a significant proportion of gillnet landings of plaice overlap with OWE areas, suggesting the gillnet fishery could lose up to 50% of its landings when offshore wind farms are closed for fisheries (Stelzenmüller et al., 2016). The types of fishing and the types of fishing gear that are able to operate within offshore wind farms will influence the distribution of both industries. However, optimising sea space for nature recovery and climate is vital for sustainable fisheries and must be at the forefront of colocation discussions (RSPB, 2022).

Brown crabs associate with turbine foundations which may therefore serve as nurseries (Hooper & Austen, 2014) and there has been some success with lobster fisheries around some Ørsted offshore wind farms (Get Nature Positive 2023). Other successful multi-use pilot projects with offshore renewable energy and fishers include examples of cooperation in the Baltic Sea which helped define corridors for cables and pipelines that minimised the crossing of the underwater infrastructure by fishers (BalticLINes Interreg project) and fishermen working part-time for offshore wind farms in Germany and Denmark (EC, 2020b).

However, several obstacles remain that hinder the colocation of fisheries and OWE, including legal issues, implementation of safety regulations, delineation of minimum requirements for fishing vessels (such as capacities, quotas, technical equipment), implementation of a licensing process, issues around insurance and scoping for financial subsidies (Christie et al., 2014; Stelzenmüller et al., 2016). There is also often a lack of trust and collaboration between the different sectors (Hooper et al., 2018). Even if it is legally permitted, many people in the fishing industry would avoid fishing within an offshore wind farm because of worries over many of these issues, especially safety (Christie et al., 2014). Changes in risk perceptions are likely to lead to a reduction in spatial restrictions for fisheries around offshore wind farms in future (EC, 2023h) and there is evidence that is already happening. For example, in the German EEZ of the North Sea, as a result of lobbying from the fishing sector, passive gear fisheries such as brown crab are being considered within 300 m of the offshore wind farm (Stelzenmüller et al., 2021).

Potential for fisheries to colocate with OWE is site specific and depends on environmental conditions, wind farm design and the risk perception of fishers and developers (Hooper et al., 2018). The potential for colocation is also specific to different fisheries; for example, there is evidence that spillover effects from offshore wind farms may favour fishing of various whitefish species like cod but flatfish are less abundant and so not suitable to fish (Hooper at al., 2018). Furthermore, colocation opportunities are linked to distance offshore, with more opportunities for colocation of OWE and fisheries in areas up to 100 km offshore and with water depths above 120 m (Gusatu et al., 2020). Successful colocation will doubtless depend on more meaningful inclusion of fisheries representatives in planning and decision-making around offshore wind farm planning processes and more effort to assess the effects of offshore wind farms on fishing (Haggett et al., 2020). A better understanding of the impact of offshore wind farms on fish species is also needed to inform the debate and the options. For example, it is still unclear if increases in some fish species around offshore wind farms is simply an aggregation or a genuine increase in biomass (Hooper et al., 2018).

In conclusion, the main scope for colocation of fisheries within offshore wind farms is probably passive fisheries, such as the use of crab and lobster pots. However, other fisheries may be exploited outside and near the wind farms to benefit from potential spillover effects. There is also a certain amount of interest in recreational fishing around OWE, with some successful examples (e.g., Fayram & De Risi, 2007; Kafas, 2017; Hooper et al., 2017; Ten Brink & Dalton, 2018; EC, 2023h). As well as passive commercial fisheries, more efforts could therefore be made to explore the options for viable recreational fisheries around offshore wind farms.

4.1.2 Aquaculture and mariculture

Aquaculture and OWE could be synergetic sectors (UN, 2021). Research and pilot projects have tested the feasibility and viability of aquaculture or mariculture in or alongside offshore wind farms, mostly focusing on bivalve molluscs (mussels and oysters), decapod crustaceans (such as crabs and lobsters) and seaweed (e.g., Gimpel et al., 2015; Buck et al., 2017; Di Tullio et al., 2018; Demmer et al., 2022). For example, the EU MERMAID project identified environmental benefits from different combinations of aquaculture and offshore renewable energy systems, resulting in pilot projects in Belgium, France, Germany, The Netherlands, Portugal and Spain, on molluscs, algae and multi-use offshore platforms (EC, 2020b). The EU is now funding pilot projects to further advance the understanding of colocation options. These projects include the ULTFARMS project for mussel and seaweed aquaculture and habitat restoration in four countries in the North Sea and Baltic Sea (ULTFARMS, 2023), the OLAMUR project in Denmark, Estonia and Germany where seaweed and blue mussels will be grown within windfarms or in the vicinity of a trout farm (EC, 2023k), and the Ghent University UNITED project (Ghent University, 2023) looking at flat oysters and seaweed in Belgium. These are promising developments, although only Portugal has expressly incentivised colocation of OWE and aquaculture (WWF EPO, 2022c). One factor affecting success, as demonstrated by pilot with mussels in the North Hoyle offshore wind farm in the Irish Sea, is clear agreement and protocols between the stakeholders (Hooper et al., 2018). This includes addressing food safety. For example, public standards, the Food Safety System Certification 22000 standard, and the Marine Stewardship Council/Aquaculture Stewardship Council standards have been proposed for seaweed farming in offshore wind farms (Banach et al., 2020).

An assessment in East Asia (Tullberg et al., 2022) suggested the colocation of finfish aquaculture and seaweed farming with OWE shows the greatest synergistic benefits for marine space usage, decarbonisation, and nutrient management, but queries were raised about the economic viability of the enterprise. If seaweed is considered, its combination with higher value aquaculture products may be required to improve economic viability (Tullberg et al., 2022). In the UK, bivalve mollusc aquaculture is seen as the most feasible colocation option, especially as relevant structures could be attached to OWE infrastructure, and some maintenance and monitoring services could be shared between the two sectors (Hooper et al., 2018). An estimated cost reduction of about 10% is feasible if the offshore wind and offshore aquaculture sectors shared operation and maintenance costs (Röckmann et al., 2017). The precise economic value associated with these benefits of collaboration and colocation depend on the scale, location, and nature of the offshore wind farm and the aquaculture and the natural resources they affect (Kite-Powell, 2017).

Overall, the economic value of colocated fisheries and aquaculture to the fishing industry is not clear or cannot yet be validated (Hooper et al., 2018; van Hoey et al., 2021) but will need to be if colocation is to work. New integrated multi-trophic aquaculture approaches should also be explored, as they offer opportunities to diversify cultured species, and to add taxa such as sea cucumbers, while improving income and the environment (Grosso et al., 2021; Cutajar et al., 2022).

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European seas and coasts are subject to a diverse array of human uses and activities.

4.2 Colocating Offshore Wind Energy with Other Renewable Energy Infrastructure

There have been several studies into the feasibility of combining offshore wind and wave energy (Hosseinzadeh et al., 2023) and a number of European sites have been identified as potentially suitable (e.g., Vasileiou et al., 2017; Weiss et al., 2018; Azzellino et al., 2019). However, there is no common agreement on all the necessary site selection criteria to optimise colocation (Hosseinzadeh et al., 2023).

Solar panels offer another opportunity for colocating renewable energy generation technologies. Integrating floating photovoltaics into offshore wind farms will increase power conversion efficiency (Li et al., 2023). However, some of the environmental impacts are poorly understood. More research is needed regarding the interactions of floating solar energy with aquatic habitats and species, especially those dependent on solar radiation, such as corals, seagrass and kelp forests (UN, 2021), and on the effects of shading on water evaporation and on water chemistry, including nitrification and deoxygenation (Exley et al., 2021).

Overall, colocation of wave and solar energy with OWE has gained limited traction to date. Its further exploration and develop is likely to be in the context of multi-purpose platforms (see below).

4.3 Colocating Offshore Wind Energy with Maritime Transport Routes

Offshore wind farms pose a navigation and safety risk for shipping and vessel traffic is often prohibited or restricted (e.g., Tsai et al., 2021; EC, 2023i). In turn, accidents may pose a pollution risk to any colocated fisheries or aquaculture (Banach et al., 2020). However, the EU Strategy to Harness the Potential of Offshore Renewable Energy notes that "the development of energy infrastructures is not incompatible with shipping routes" (EC, 2020b) and, in some countries, shipping has been allowed to traverse offshore wind farms. In the Netherlands, for example, shipping is permitted through three offshore wind farms (Offshore Windpark Egmond aan Zee, Prinses Amalia Windpark and Luchterduinen); this has been enabled through the use of key regulations, such as limiting transit to daytime for ships up to 24 m length that have functioning and active VHF and AIS installations, and respect for a safety zone of 50 m around the turbines (EC, 2023i). Another way to facilitate colocation is to reduce OWE infrastructure in key shipping lanes. For example, cooperation between stakeholders in the Baltic Sea (through the BalticLINes Interreg project) helped define corridors for cables and pipelines that minimised the crossing of shipping lanes (EC, 2020b).

As turbines evolve and continue to increase in size, the space between them will also increase and could expand the scope for allowing passage of at least some maritime transport (Li et al., 2023). The introduction of multi-used zoning in offshore wind farms (see below) could also enhance colocation with shipping. However, it has already been shown that the ship traffic associated with offshore wind farm maintenance can affect biodiversity (e.g., Mendel et al., 2019; Bennun et al., 2021) and so any additional shipping should only be facilitated in areas where there are no sensitive species or habitats present.

4.4 Colocating Offshore Wind Energy with Tourism

There are sometimes concerns among local stakeholders about potential negative impacts of offshore wind farms on tourism in coastal waters (e.g., Gee, 2010; Rudolph, 2014), and opposition to wind farms often relates to the expected impact on business interests and tourism (Dimitropoulos & Kontoleon, 2009; Wolsink, 2010). However, research indicates that the overall impact on tourism is relatively benign, and sometimes positive (Westerberg et al., 2013; Glasson et al., 2022). Studies in Denmark and Sweden found no significant decrease in tourism or holiday rentals after the construction of offshore wind farms (Kuehn, 2005; Westerberg et al., 2013) and several studies across Europe found that, in general, the majority of people would not reduce their visits to an area due to the presence of wind turbines (Westerberg et al., 2013). Indeed, there is a growing body of work looking into the potential opportunities of tourism around OWE (see Lal et al., 2021 and Glasson et al., 2022 for recent reviews). As part of the MUSES Multi-Use in European Seas project, funded by the EU Horizon 2020, ten case study areas in the Atlantic, North Sea, Baltic Sea and Mediterranean Sea were identified to assess potential synergies and challenges for 16 of the most promising multi-uses combinations (EC, 2023j). Several opportunities were identified by the project for tourism and offshore wind farms (e.g., Varona et al., 2017a,b; Bocci et al., 2018).

A range of tourist attractions are possible based on offshore wind farms, including information centres, information boards, viewing platforms with telescopes, boat tours, sightseeing flights, routes for motorboats and sailing boats, offshore restaurants and merchandising products (Albrecht et al., 2015). In Bremerhaven, Germany, the local harbour tour bus (*hafenbus*) offered special "tour de wind" trips to see ports and explain wind energy infrastructure (Albrecht et al., 2015; Varona et al., 2017a; TripAdvisor, 2023). In Middelgrunden, Denmark, tourists can climb a tower on one of the turbines, as well as visit an offshore information centre and take boat tours (Varona et al., 2017b; Bocci et al., 2018). Coastal tourism activities may in some cases compete for space with fishing, but tourists are also an important source of demand for fish products, especially from small-scale coastal fleets (EC Directorate-General for Maritime Affairs and Fisheries, 2022). And, of course, recreational fishing in and around offshore wind farms could be an attraction for some tourists.

In the UK, the Scroby Sands offshore wind farm visitor centre received 30,000 visitors during its first six months of operation (BWEA, 2006). The first large-scale offshore wind farm in Southeast Asia (20 turbines in the Bangui Bay in the Philippines) is reported as having revitalised the province’s local tourism industry by attracting visitors curious to see the turbines (Jimeno, 2007). A green image may, in turn, further facilitate increased destination loyalty or recommending behaviour (Chen & Tsai, 2007). Education opportunities could also be linked to offshore wind farm visits, with the possibility of engaging tourists and schoolchildren in discussions about climate change (Glasson et al., 2022).

Of course, there is always a chance that the interest in offshore wind turbines will fade as the novelty wears off and they are visible in more and more places. Nonetheless, there seems to be a lot of potential for using offshore wind farms as tourist attractions. Tourism ventures already demonstrating some degree of success should be explored more extensively across Europe, with relevant stakeholders, to identify possibilities to colocate activities in a mutually beneficial way. All of the ventures under consideration, though, will need to ensure they do not cause any additional environmental risks or impacts.

5. Conclusions and Recommendations

The human population has doubled in the last 50 years and the world is now experiencing a triple planetary crisis of climate change, biodiversity loss, and pollution (UNEP, 2021). Marine resources continue to be overexploited, and only 3% of the world's oceans are estimated to be free from human pressures (IPBES, 2019). Climate change impacts are increasing and leading to massive threats for many species as well as economic activities (IPCC, 2023). European countries have justifiably increased their commitments for the installation of renewable energy, and offshore wind energy is a vital tool to reducing carbon emissions and tackling climate change. We therefore need to ensure that a sector aimed at reducing one third of the planetary crisis (climate change) can also contribute to mitigating the other two thirds (biodiversity loss and pollution). This is even more important given the required speed and scale of the interventions needed to meet the commitments by European states to attain climate and energy security while at the same time improving the protection of marine ecosystems and the area under strict protection.

This review found that European MPAs are under intense pressure from a range of human activities and inadequately managed. Even though offshore wind farms appear to be less environmentally damaging than many other human uses of the ocean, colocation with MPAs risks impacting species and habitats, creating communities that differ from those found in natural habitats, and introducing alien invasives. This can consequently jeopardise the attainment of MPA goals. Several other maritime activities, especially passive fisheries, aquaculture, shipping and tourism, may be more compatible than MPAs for colocation with offshore wind farms.

Marine protected area networks and offshore wind farms will continue to expand across Europe in coming years to attain global and regional energy and biodiversity objectives. Based on the findings of this review, several preliminary recommendations can be made to help the diverse stakeholders involved in European MSP create the enabling conditions for the colocation of sustainable economic development activities without jeopardising the conservation of the marine ecosystems upon which, ultimately, most other activities depend.

5.1 Improving MPA Management and Protection

Recommendation 1: Governments and their partners need to improve the management and protection of MPAs and better integrate MPAs into maritime spatial planning, minimising colocation with other activities.

Efforts need to be made to enhance the conservation outcomes of MPAs through appropriate investment, capacity building and enforcement of no-take zones. An increase in ocean protection not only conserves biodiversity but also boosts the yield of fisheries and secures marine carbon stocks (Vandeperre et al., 2011; Sala et al., 2021). Therefore, setting aside ocean space for MPAs may reduce the immediate revenue for some users, but in the long-term it has economic as well as an environmental benefits. As the EU biodiversity strategy highlights, "studies on marine systems estimate that every Euro invested in marine protected areas would generate a return of at least €319" (EU, 2020). It also quotes figures estimating that the benefits of Natura 2000 are valued at between €200-300 billion per year and likely to support as many as 500,000 additional jobs.

OECMs should be identified in inshore marine habitats to enhance the connectivity of area-based conservation efforts. European states need to clarify the designation process for OECMs and the feasibility and desirability of any offshore wind farms becoming OECMs needs to be explored and clarified to better inform European policy. Are there any conditions under which colocation might be possible? The most obvious option would be to consider offshore wind farms that have successfully enhanced nature or restored key habitats to become OECMs. This would need to be considered in the context of potential decommissioning plans, but might help ensure any benefit to nature gained in the offshore wind farm is not lost during repowering or when operations cease.

For Europe and the rest of the world to attain its biodiversity goals, MPAs and OECMs must contribute more effectively to preventing extinctions and retaining intact ecosystems (Maxwell et al., 2020). While prohibiting trawling, dredging, shipping and other potentially damaging maritime activities may require less enforcement in offshore wind farms than in MPAs due to the concerns of other ocean users about colliding with turbines or cables, building OWE infrastructure in MPAs should not be seen as a means of increasing protection, for all the risks outlined above and for adding stress to an already stressed environment. Therefore, in order to meet conservation and development goals, European states need to ensure that "the main priority of all MPAs is conservation of biodiversity, not economic opportunity" (WWF EPO, 2019). Given that there is "limited available evidence of OWE sites meeting ecological MPA requirements if preserving naturally occurring habitats is the main goal of MPA designation" (Ashley et al., 2014), "the potential for an MPA and a conventional offshore wind farm to work in synergy is limited" (Sanders et al., 2017). "The direct and indirect environmental impacts of energy installations and issues of protecting 'natural' habitats will limit the extent to which co-located sites can contribute to [MPA] network targets for protection" (Thurstan et al., 2018). OWE should therefore be avoided in MPAs and OECMs.

Regional and national policies sometimes allow for developments such as OWE in MPAs if the impacts are insignificant. There needs to be enhanced clarity and a more common understanding of the definition, interpretation and estimation of significance for any developments within an MPA or OECM. This clause should not be used as a means of undermining protection legislation and further degrading already threatened protected and conserved areas.

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Fowlsheugh Nature Reserve in north-east Scotland is a coastal MPA established to maintain populations of breeding seabirds. It lies within 30 km of an offshore wind farm.

Relevant maritime spatial planning guidelines should be followed (e.g., Ehler & Douvere, 2009; Veidemane et al., 2017; UNESCO-IOC/European Commission, 2021), and the best available data used to inform decisions, especially on any types of colocation. "Permitting wind-farm developments for which the siting has been underpinned by solid strategic planning with careful and early consideration of biodiversity will be much smoother than if biodiversity concerns in wind-farm projects are only addressed later in the process" (EU, 2020). Environmental concepts of relevance for the offshore wind energy sector include the ecosystem-based approach and the Precautionary Principle (Stephenson, 2022), and this review has highlighted the need for both to be applied more consistently. The ecological impacts of all aspects of development should be assessed through sensitivity mapping, EIAs and SEAs to identify which areas of the seabed are appropriate for sustainable development and to maximise colocation (RSPB, 2022). Socio-economic factors also need to be considered in both OWE and MPA planning (e.g., Pascual et al., 2016; Soukissian et al., 2016). These measures will help ensure offshore wind farm avoid important biodiversity areas and sensitive sites, especially those with slow recovering or highly sensitive species. These best practices will be easier to follow if there is a general move away from designating and managing MPAs separately from broader MSP, and fully integrating MPAs and OECMs into MSP.

5.2 Exploring Colocation with Other Maritime Activities

Recommendation 2: Opportunities for the colocation of offshore wind energy with other maritime activities should be optimised through data-driven maritime spatial planning and by addressing key obstacles

The only solution to facilitate apparently conflicting uses of European seas is for participatory, science-based maritime spatial planning that optimizes colocation of certain objectives. Colocation of activities is an ambition and a necessity, especially in some of the busiest and most over-used areas of the ocean. Using some OWE sites for passive fishing, aquaculture, shipping, tourism (and maybe other forms of renewable energy), while minimising additional stresses on MPAs, could help improve the efficiency of human use of the marine environment and maximise the benefits to people and nature. Decisions for colocation will need to be made in the context of the best available scientific evidence and integrated MSP, and all colocated activities subjected to rigorous, standardised monitoring of their effectiveness and on their environmental impacts to inform adaptive management and future planning. Governments, companies and other stakeholders will need to be pragmatic and colocate activities where it does not jeopardise the conservation of marine ecosystems upon which, ultimately, most of the other activities depend.

While several maritime activities may be compatible with OWE in some instances, specific activities will require specific solutions to ensure effective colocation. A number of cross-cutting issues also need to be addressed.

a. Common definitions need to be agreed and adopted

Colocation needs to be clearly defined. In the context of MSP, it might be better to think of colocation as one of four different types of ocean multi-use (Table 2; Schupp et al., 2019). If the use of ocean space is to be maximised, all four options will need to be employed to ensure maritime activities can continue. For OWE, Type 1, Type 2 and Type 3 (where activities occur in the same place and the same time with different levels of shared infrastructure) should be explored in more depth.

For Type 1 (multi-purpose/multi-functional), the development of multi-use platforms may be the key (e.g., Abhinav et al., 2020; Aryai et al., 2021; Demmer et al 2022; Ramos et al., 2022; DNV, 2023). These specialised infrastructures have been developed to facilitate combinations of offshore wind with activities such as wave energy, aquaculture and desalination (Abhinav et al., 2020; Dalton et al., 2019), but few have yet come to fruition (DNV, 2023). For Type 2 (symbiotic use), where at least some services on land and at sea are shared, criteria will need to be agreed to identify viable sites and relevant benefit and cost-sharing agreements will need to be developed. Aquaculture, passive fisheries and tourism may all offer suitable test cases. For Type 3 (coexistence/colocation), where activities take place in the same place at the same time but without any shared infrastructure or services, the key will be to clarify the rights and responsibilities of different users, to define cooperation and mediation mechanisms and build capacity within the relevant collaborating industries for colocation (Schupp et al., 2019).

Table 2. Typology of ocean multi-use. Adapted from Schupp et al. (2019). Types are ordered by decreasing degree of connectivity between uses and users.

Type	Description	Examples
1 Multipurpose/ multi-functional	Takes place in the same area, at the same time, with shared services and core infrastructure	Marine renewable energy and desalination
2 Symbiotic use	Takes place in the same area, at the same time, and peripheral infrastructure or services are shared	Aquaculture in offshore wind farms
3 Coexistence/ colocation	Takes place in the same area, at the same time	Fisheries in offshore wind farms
4 Subsequent use/repurposing	Takes place in the same ocean space but subsequently	Repurposing offshore structures for new uses (e.g., tourism, aquaculture, conservation)

b. Stakeholder collaboration needs to be improved

The diverse regulatory, technical and socio-economic obstacles to colocation of activities in MSP need to be resolved, from legal issues to safety regulations to licensing and subsidies, and this will require active collaboration between all stakeholders (Stelzenmüller et al., 2016; Bocci et al., 2018; van den Burg et al., 2020; Steins et al., 2021). Any efforts to colocate activities in the ocean should include the relevant industry subsectors in MSP and consider colocation from the outset (Yates et al., 2015). The challenges should not be underestimated. For example, for North Sea fishing communities, maritime spatial planning holds risks as well as opportunities, depending on which institutions are formed and what role they are allowed to play in the planning process (Jentoft & Knol, 2014). An MPA in Belgium (the Vlakte van de Raan SAC) was declassified, partly because its original designation had not involved any local stakeholder engagement, as well as conflict over a potential wind farm (Pecceu et al., 2016). Communities of practice, to bring stakeholders together to share experiences and lessons, has proven useful in some cases to enhance dialogue and to tackle the wicked problem of MSP with diverse stakeholders (Steins et al., 2021).

c. Research needs to fill gaps in knowledge that block colocation

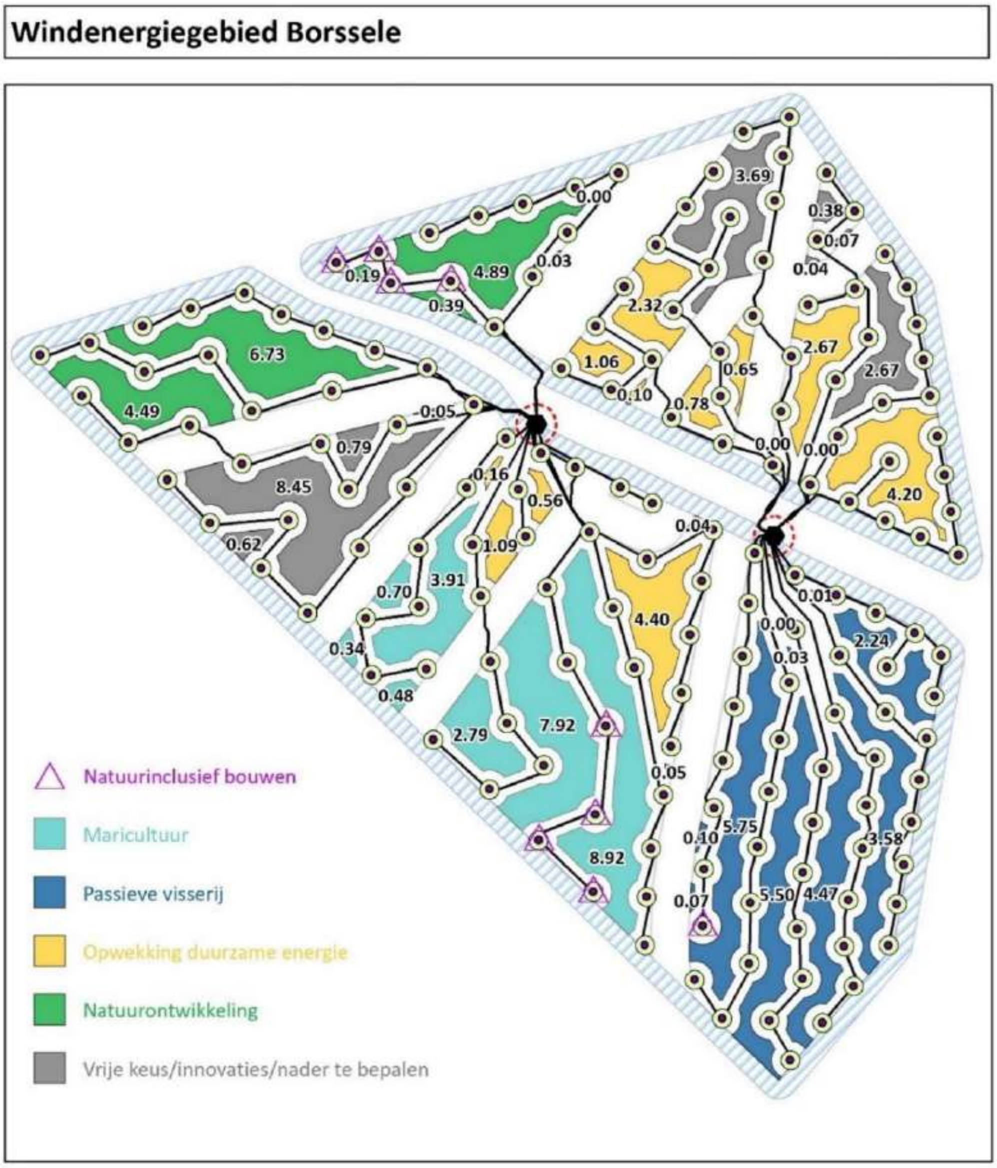
As well as finding ways of engaging stakeholders in appropriate and fruitful planning processes, more research will help unblock certain obstacles. For example, evaluating the impacts of colocation is highly complex because of the many potential socio-economic, technological and environmental interactions and much of the data required to inform those evaluations of colocation potential are unavailable (Thurstan et al., 2018). In particular, further research is needed into the ecological and socio-economic issues surrounding fishery co-location potential with OWE (Hooper & Austen, 2014). For aquaculture, the current paucity of experimental pilots to test technical and economic feasibility, in combination with the lack of clear licensing procedures and regulations, is inhibiting the development of aquaculture in offshore wind farms (Van Hoey et al., 2021).

The EU Strategy to Harness the Potential of Offshore Renewable Energy (EC, 2020b) notes that research and experimentation should be fostered to advance multi-use pilot projects and make the multi-use approach more operational and attractive to investors. This could be facilitated within regional cooperation fora. Several studies show that offshore wind farm developers are not intrinsically motivated to engage in multi-use, as it is not part of their core business and might increase their operating costs. (Van Hoey et al., 2021). Therefore, when economically viable multi-use systems within offshore wind farms have been developed, Member States could stimulate and enhance opportunities for co-location with incentives (e.g., criteria in tender procedures, area passports, clearer licensing procedures).

Box 2. An example of multi-zoning in an offshore wind farm.

As part of its North Sea Policy Document 2016-2021, the government of the Netherlands (2015) decided on a system of multiple use of marine areas. This included opening up offshore wind farm to shared use with: mariculture (including shellfish and seaweed); other forms of sustainable energy generation and storage (including solar or tidal energy); nature enhancement projects (e.g., oyster recovery, shelters for fish, artificial reefs); and passive fishing (including using baskets for crabs and lobsters). A good example of this policy in action is the use of a zoning map (or Handreiking area passport; Fig. 2) which was drawn up for the Borssele wind energy area (*Windenergiegebied Borssele*). Based on area-specific characteristics, this map indicates where and which forms of shared use have the most favourable prospects and which can then be applied, subject to a permit being issued under the Dutch Water Act (Wind op zee, 2023). If we are to maximise the efficiency with which European seas are used, then more offshore wind farms will need to be developed with a consideration for multi-use zoning such as this.

Figure 2. Map showing zonation of maritime activities in the Borssele wind farm in the Netherlands. Pale blue areas - mariculture; Dark blue - passive fishing (e.g., lobster and crab pots); Yellow - other sustainable energy generation (e.g., solar, tidal); Green – nature support projects (e.g., oyster recovery, fish shelters, artificial reefs); Grey – to be determined. Source: Wind op zee (2023).



d. Pilots for multi-use zoning and multi-purpose platforms need to be expanded

Collaboration is key to successful MSP and the planning of any colocation activities (e.g., van den Burg et al., 2020; Steins et al., 2021; Glasson et al., 2022) and any attempt to colocate activities will likely need some adaptation of plans and systems from the different actors. OWE structures may need to be adapted by, for example, rerouting cables or spacing turbines to allow sufficient space for the colocated activity. Fisheries within an offshore wind farm will need to use gear that is compatible with the OWE infrastructure and grid. But these adaptations can also lead to greater collaboration on operations and monitoring.

Several studies have looked into criteria and indices for identifying potentially suitable sites for colocating maritime activities such as offshore wind farm and mussel farming (Benassai et al., 2014; Di Tullio et al., 2018) or assessing risks (e.g., van den Burg et al., 2020). Colocating activities in the context of MSP might benefit from the use of future-oriented planning approaches such as the development of alternative scenarios for stakeholders to deliberate on (see, e.g., Ehler & Douvere, 2009; McGowan et al., 2019). Any multi-use or colocation plans will also need to follow standard best practice in conducting EIAs and SEAs to avoid environmental impacts. More information also needs to be shared on good examples of multi-use planning in action. One such example can be found in the Netherlands (Box 2).

5.3 Reducing Impacts and Enhancing Biodiversity Around Offshore Wind Farms

Recommendation 3: Best practices and innovations to reduce environmental impacts and enhance biodiversity around offshore wind farms need to be expanded

Mitigation and restoration work should minimise the changes in the natural ecosystem around all offshore wind farms. As per recommendation 2 and as explained in section 3.4, these measures will need to be applied even more extensively and rigorously in the instances where OWE is developed within an MPA, with a more specific focus on the species and habitats that are a focus of the MPA goals.

a. Mitigation measures to reduce impacts need to be enhanced around all offshore wind farms

Many of the known pressures on biodiversity from OWE can be addressed through a variety of mitigation strategies that either reduce the magnitude of the pressure or its impact on species and habitats. Examples include: bubble curtains, acoustic deterrents and the use of low-noise foundations that can mitigate the effects of pile driving noise on marine mammals (Dähne et al., 2017; Koschinski & Lüdemann, 2020; NER & DNV, 2021); minimising vessel traffic and other disturbance during times of day or seasons when sensitive species are feeding or breeding (Bennun et al., 2021); stopping construction when marine mammals are detected in the area by observers or passive acoustic monitoring devices (e.g., Sanders et al., 2017); shutdown on demand approaches that stop turbines when there is imminent risk of bird collisions (e.g., Tomé et al., 2017; Bennun et al., 2021); A comprehensive list of mitigation measures is presented by Bennun et al. (2021).

New innovations also need to be developed further and tested, ranging from painting turbine blades in colours that reduce birds strikes (May et al., 2020) to using muti-sensor arrays to improve monitoring (e.g., Lagerveld et al., 2020; Largey et al., 2021). All measures should be monitored to gauge their effectiveness. It should also be noted that not all impacts can be mitigated, and it may not be possible to avoid the displacement of sensitive species during construction.

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Marine mammals such as dolphins and porpoises are primarily affected by the construction noise of offshore wind farm development. Mitigation measures to reduce impacts on marine mammals include use of bubble curtains and low-noise foundations.

b. Actions to proactively promote nature need to be enhanced in and around all offshore wind farms

Efforts need to be scaled up to enhance nature in offshore wind farms, especially those in degraded areas. While the populations and habitats of some impacted taxa cannot be improved or restored (e.g., birds and bats displaced by construction or at risk of collision), certain marine species of fish and invertebrates can be enhanced. The efforts made by offshore energy companies and TSOs to work with governments, researchers and NGOs to apply appropriate nature-inclusive designs and restoration activities for relevant habitats and taxa need to be acknowledged, encouraged and continued, with monitoring and data sharing ensuring any failures are learned from and successes replicated.

Nature-inclusive design (NID) is a key concept for the OWE sector (Stephenson, 2022) and refers to options that can be integrated in, or added to, the design of an anthropogenic structure with the aim to enhance ecological functioning (Hermans et al., 2020). NID is increasingly being used to enhance the suitability of habitats on offshore wind structures for native species (e.g., Perkol-Finkel et al., 2018; Sella et al., 2022; Nordic Energy Research, 2023). Designs can be integrated into a wind turbine foundation, an offshore substation, a scour protection layer, or a cable protection measure (Hermans et al., 2020). Such designs offer many opportunities for offshore wind farm to enhance nature, including acting as catalysts for nature recovery (e.g.: monopiles form hard substrates for settlement of sea life; optimised scour protection and cable/pipeline protection to encourage biodiversity; artificial reefs can be established as they are safe from bottom-trawling), and as shelters for marine life (e.g.: resting platforms for seals; crevices for use by crustaceans; fish hotels and biohuts; standalone units acting as artificial reefs) (Steins et al., 2021; Nordic Energy Research, 2023). A large part of the footprint of an offshore wind farm is the scour protection, which often consists of rocks that are positioned on the seabed to prevent erosion. However, if designed appropriated, scour protection can act as artificial reefs, providing shelter, nursery, reproduction, and/or feeding opportunities (Glarou et al., 2020). Coolen et al. (2020) recommend adding as much rock dump or scour protection as possible in various sizes around OWE structures, to increase local habitat complexity and benefit epibenthic species that inhabit natural reefs.

The Government of the Netherlands tendering process requires offshore wind foundations to be built with nature-enhancing solutions (NER & DNV, 2021). NID also offers opportunities for the colocation of activities, by either contributing to food production through aquaculture or passive fisheries, or acting as physical borders around conservation areas. However, the success of NID needs to be monitored to learn from experience and improve efficiency in future (DNV, 2023).

As well as designing and adapting the OWE infrastructure, offshore wind farm areas can be used to reintroduce native species and restore habitats. The Rich North Sea Programme, comanaged by Natuur & Milieu and Stichting De Noordzee (North Sea Foundation), has demonstrated success with using oyster tables to help restore oyster reefs in the Dutch North Sea and reintroduce flat oysters (The Rich North Sea, 2023). Other efforts have also showed promise using offshore wind farms to introduce oysters (e.g., Robertson et al., 2021).

The differences between NID and habitat or ecosystem restoration are sometimes confused, with some actors advocating NID as a way of, for example, restoring degraded habitats (Nordic Energy Research, 2023) or somehow allowing colocation with MPAs (DNV, 2023). While NID is about improving the composition of human structures added to marine nature, enhancing its environment beyond the intended function for human needs such as energy production, restoration is about recovering damaged natural ecosystems and so, by definition, is not NID (Stephenson, 2022).

Success in enhancing nature around offshore wind farms has implications for upgrading and decommissioning (Fowler et al., 2020). Species communities and habitats that develop on scour protection or as part of other efforts at NID or restoration should be considered in decommissioning decisions and in at least some cases left in place (Coolen & Jak, 2018). Depending on life cycles and species status (e.g., OSPAR protected or non-native), different leave-in-place options should be considered during decommissioning (e.g., leave the foundations as they are, remove part of the foundations to depths with limited risk of non-indigenous colonisation, or remove fully). As discussed above, these enhanced or restored areas within offshore wind farms may even provide opportunities to create OECMs. As suggested for the Mediterranean, “a beneficially placed offshore wind farm is one in a degraded area where the underwater structures could help restore the damaged ecosystem and increase biodiversity; it could then operate as an OECM” (Lloret et al., 2022).

Recommendation 4: Where colocation of OWE with MPAs does occur, mitigation actions and proactive conservation efforts need to be optimised

Although this review concludes that siting offshore wind farms in MPAs and OECMs is risky and should be avoided, it will occur in some countries, whether by design (e.g., in MPAs of IUCN category IV to VI where conservation goals are not expected to be affected) or by uncoordinated planning. As described in section 3.4, in such instances, avoidance and minimisation measures will need to be maximised and applied thoroughly, and vigorous, proactive efforts made to protect and restore native species and habitats that are the focus of the MPA. Any restoration efforts will need to be as suitable, feasible and appropriate as possible, based on the goals of the MPA.

5.4 Monitoring and Adaptive Management

Recommendation 5: Systematic monitoring, research and data sharing is required to track the state of marine species and habitats in both MPAs and in and around offshore wind farms to inform MSP and adaptive management and to fill key knowledge gaps

The availability of data and knowledge is key to the maritime spatial planning process (e.g., Trouillet & Jay, 2021) and “can improve the quality of MSP by instigating and structuring a participative process with cross-sectoral and cross-border learning” (van den Burg et al., 2023). Increased efforts are therefore needed to enhance the available evidence base. Standard methodologies to assess and quantify the contribution of OWE to nature are also needed. As per recommendation 2, research is needed to improve our understanding of the options and approaches, trade-offs and opportunities for colocating different maritime activities with OWE.

A more integrated approach for biodiversity monitoring around OWE is essential and will require a greater level of sectoral and regional collaboration, cooperation and open data sharing than currently exists (Stephenson, 2021). More data sharing is needed across sectors and seas and stakeholders. In many cases, different sectors need the same information. For example, data on bird movements and behaviour are essential for planning MPAs (Thaxter et al., 2012) as well in sensitivity mapping of OWE (Perrow, 2019). Long-lasting monitoring close to and away from wind farms, at the surface and near the bottom of the turbines, is required to gain a better understanding of how effects radiate outward from the wind turbine and how far (Li et al., 2023) as well as to provide evidence for adaptive management of pressure mitigation measures and nature enhancement work. Monitoring methods like environmental DNA (Mauffrey et al., 2021) and baited underwater video (Griffin et al., 2016) may have a higher chance of detecting species could be an alternative to the current time-consuming and costly routine biomonitoring.

To ensure MPAs deliver the best possible benefits for marine biodiversity, there is an ongoing need to better manage and monitor MPAs, to assess achievement of MPA goals and to share knowledge and experience of the response of European marine life to pressures and the results of protection measures (EEA, 2018). In addition, more open sharing and publication of monitoring data from sites where different activities have been colocated, as well as more analyses and interpretive reports focused on MPA goals, would not only help learn lessons about long-term impact and the validity of assumptions made, but also help inform eventual decision around repowering or decommissioning these wind farms.

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A Sandwich tern (*Thalasseus sandvicensis)* flying past a wind farm in the North Sea.

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