REWILDING OUR WATERS IN AN ERA OF OFFSHORE WIND

A RESEARCH REPORT FOR REWILDING BRITAIN

REWILDING BRITAIN

Pelagos

ABOUT US

Rewilding Britain
Rewilding Britain is inspiring a movement of rewilders across Britain’s land and seas – a groundswell of hope, so that together we can ensure a wilder, nature-rich future that benefits us all. We want to see 30% of our seas restored for nature by 2030, through seascape-scale action. Help us turn the tide.

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Pelagos works collaboratively to catalyse positive change towards a thriving ocean. Working at the intersection of nature, climate and social justice, Pelagos generates insight to broaden horizons and mobilise change.

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ABOUT THIS RESEARCH REPORT

Between June 2025 and September 2025 Pelagos carried out a comprehensive desk review to inform the development of this report, commissioned by Rewilding Britain.

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1. EXECUTIVE SUMMARY

Preserving and restoring the natural and cultural resources of coastal and offshore territories while intensifying the roll-out of offshore wind development, represents one of the most important challenges for the future management of the UK marine environment.

Offshore wind energy (OWE) has emerged as a cornerstone of the UK's climate strategy, and globally it is expanding at a rapid pace. By 2050, an estimated 2000 gigawatts of offshore wind will need to be installed worldwide – requiring thousands of new turbines each year, covering more than half a million square kilometres of ocean. There are still considerable gaps in the scientific knowledge base surrounding impacts. The first offshore wind turbine was installed only a few decades ago and as a result, the world has had little time to fully understand the impacts and opportunities from OWE.

This report explores whether offshore wind could become an ally in creating a wilder Britain. It brings together evidence on ecological, social, and economic impacts and considers how offshore wind could fit within Rewilding Britain's vision of recovering nature at scale.

The science tells a nuanced story. Offshore wind farms (OWFs) are not ecologically neutral and their impacts vary dramatically across phases; construction, operation, and eventual decommissioning.

Construction is the most obviously disruptive stage. During the short but intense construction period the main impacts of OWFs relate to noise. Pile driving, dredging, and vessel traffic create intense underwater noise and seabed disturbance, driving away sensitive bird and mammal species, and displacing some species of fish. Some argue that floating turbines, which require fewer seabed interventions, appear less damaging, however they also remain less studied.

Once operational, by contrast, OWFs offer both risks and opportunities. On the positive side, fixed turbines add vertical structures to otherwise flat seabed, creating artificial reefs where mussels, barnacles and anemones congregate. In areas where fishing is excluded for safety reasons, OWFs may function as de-facto marine protected areas (DFMPAs), safeguarding seabed carbon stores and allowing ecosystems to further regenerate. As a result these accidental habitats have been shown to boost biodiversity and sometimes support the recovery of commercially important species. There is, however, concern that increases in diversity may favour opportunistic or 'invasive' species, rather than threatened or rare ones. Additionally, some argue that higher biodiversity or biomass is a result of organisms 'relocating', rather than increasing in number.

Birds are the most negatively affected by the operational phase, facing the twin risks of collision and displacement, especially in densely developed areas like the North Sea. For some species, cumulative impacts across multiple wind farms are potentially devastating, although mitigation measures are improving rapidly with technological innovations. Meanwhile, evidence on the long-term or cumulative effects on marine mammals are still emerging, with significant gaps in understanding.

A small number of available results show that, once built, the presence of OWFs in the operational phase may lead to positive changes in natural processes including turbidity, atmospheric wake and the flux of nutrients, which can have positive impacts on pelagic and benthic ecosystems.

Alongside their impacts on biodiversity, it is important to examine how OWFs also reshape coastal communities and economies. The sector promises jobs in construction, operations, and maintenance, but benefits are unevenly distributed. While around 75% of operational spending remains in the UK, much of the construction phase is outsourced abroad due to things such as imported components, foreign expertise in engineering and lack of UK manufacturing capacity. Floating wind, which requires more onshore assembly, could offer greater local economic opportunities if backed by investment in ports and supply chains.

Fishers are among the most directly affected. For many, offshore wind represents lost fishing grounds and livelihoods under threat. Yet OWFs may also provide 'spillover' benefits as fish populations rebound in no-fishing zones, highlighting the complex balance between displacement and ecological regeneration.

Beyond economics, OWFs can shape culture and identity. They alter seascapes, sparking debates about aesthetics, heritage, and sense of place. They also have the potential to build ocean literacy, reconnecting people with the coasts and seas through education, tourism, and citizen science. When projects include well designed community benefit funds or partnerships, they can empower coastal populations and strengthen public support. Without meaningful engagement, however, mistrust can quickly take root.

Financial mechanisms are increasingly shaping how OWFs intersect with large-scale marine restoration. Potential initiatives like Marine Net Gain aim to ensure that marine developments actively improve biodiversity, not just minimise harm. Funds such as the Marine Recovery Fund, SMEEF in Scotland, and Marine Fund Cymru in Wales collectively aim to direct millions of pounds toward seagrass, oyster reef, and saltmarsh restoration. Private-sector partnerships, too, are emerging, with developers collaborating with NGOs on habitat recovery projects. If properly designed, these mechanisms could ensure that offshore wind development directly contributes to rewilding Britain's seas. However it is vital they avoid becoming vehicles for greenwashing or offsetting without real ecological uplift.

Offshore wind could become a strategic ally in large-scale marine restoration if projects are carefully sited on degraded seabeds, if nature-inclusive designs are adopted from the outset, and if monitoring and adaptive management close the many knowledge gaps. Policies like Marine Net Gain can help ensure OWFs deliver ecological benefits, while exclusion zones can function as refuges from destructive fishing practices.

The future of offshore wind is also a social choice. Communities must see tangible benefits – not only in jobs and funds, but in healthier seas, thriving wildlife, and renewed connections to place. Storytelling, education, and transparency will be critical in making offshore wind feel like part of a hopeful, regenerative future rather than just another industrial imposition.

At its best, offshore wind could help Britain pioneer a new model of coexistence – where human infrastructure supports ecological recovery, where large-scale marine restoration creates new economies as well as new habitats, and where people feel empowered in shaping the seascapes of tomorrow.

Offshore wind could be part of a new kind of 'wild' – rather than returning to a pristine past, a wilder future could be a resilient future where human ingenuity supports ecological recovery and embraces the coexistence between nature and infrastructure.

2. SCOPE AND LIMITATIONS

It is estimated that 2000 Gigawatts of OWFs will need to be installed worldwide by 2050[1] – a huge increase from the 35 Gigawatts installed back in 2020. This will require around 5000 new turbines installed every year, occupying more than 500,000 km2 of ocean. Experts predict that by 2035, 11–25% of all new offshore projects globally will feature floating as opposed to fixed foundations[2].

According to 2025 figures, China leads the global offshore wind industry with the highest number of operational OWFs (138), followed by the United Kingdom (51), Vietnam (42) and Germany (32)[3]. In the coming decade countries including Australia, Brazil, France, India, Italy, Poland and Saudi Arabia all aim to build their first OWF.

Preserving and restoring the natural and cultural resources of coastal and offshore territories while intensifying renewable marine energies, represents one of the most important challenges for the future management of marine environments.

This systematic review considers the effects of OWE on ecosystems and society and how compatible the structures might be with a wilder future. In the last century, the UK has lost up to 92% of its seagrass and 95% of its native oyster reefs. Many marine animals feature on the International Union for Conservation of Nature's (IUCN's) red list and a WWF report has shown that over the past 50 years the average size of marine wild vertebrate species has fallen by 56%[4].

Marine rewilding is the large-scale restoration of marine ecosystems to the point where nature can take care of itself and accelerate the recovery of nearby marine areas. Rewilding seeks to reinstate natural processes and, where appropriate, missing species – allowing them to shape the seascape and the habitats within. Rewilding encourages a balance between people and the rest of nature, so that they can thrive together. It can support and create new opportunities in coastal economies, allow living systems to provide the ecological functions on which we all depend, and help people reconnect with the marine environment. The principles of marine rewilding are:

- Work at ocean scale;
- Let our ocean lead;
- Support our ocean and communities together;
- Create resilient local economies;
- Secure benefits for the long term.

It is important to note that there are still considerable gaps in the scientific knowledge base surrounding impacts. The first offshore wind turbine was installed only a few decades ago – in 1991 off Denmark (and 2000 in the UK) – and as a result, the world has had little time to understand the impacts and opportunities from OWE. Despite research on OWF growing exponentially over the last 20 years, the net positive or negative impacts of OWF on many marine populations remains unclear. Of the evidence that does exist it is worth noting the following:

- Quite a lot of the studies look at single pressures[5] and impacts are rarely considered through a whole-ecosystem perspective. It is well-known that human activities can produce several co-occurring pressures, which can result in interconnected impacts on the ecosystem.
- Most publications are from studies conducted at more localised scales[6] (e.g. in shallow waters, close to the coast, with few turbines etc) so findings from one OWF may not necessarily be applicable to or valid for another OWF.
- Studies are mostly focused on the short-term and long-term effects are rarely investigated.
- There are gaps in the research regarding the different stages of an OWFs development – construction, operation, maintenance and decommissioning – and the different types

of windfarm. In particular there is insufficient evidence on the impacts of decommissioning and on deeper-water floating structures as these are both in their infancy.

- The socio-economic impacts of OWE have received little attention compared with the biophysical impacts[7].
- A recent study found that overall more than 86% of possible offshore wind farm impacts on ecosystem services are still unknown[8]. Grey literature portrays a largely negative (71%) view of ecosystem service impacts and fails to represent many positive ecosystem services impacts reported in the primary literature[9].
- The lack of overall data continues to confound the ability to differentiate between real and perceived risks.

Within this complex picture we have triangulated evidence to identify how to harness offshore wind for a wilder future.

3. ECOLOGICAL IMPACTS AND OPPORTUNITIES

In a recent review of 867 findings on the ecological impacts of OWE it identified, biological pressures as the most-studied pressure category (63%)[10]. The most frequently researched pressure related to biological disturbance and noise input. Most findings (87%) were reported for species – majoritively birds, followed by fish and mammals. This was followed by ecosystem structure, functions and processes (11%), and then habitats (3%).

Among the 867 publications, 72% reported negative impacts, while 13% were positive. 54% of these were reported as being high or moderate magnitude, while 32% were low or negligible. While there is a relatively high degree of agreement regarding impact type (e.g. positive or negative) of offshore wind devices on ecosystem elements, certainty regarding impact magnitude is relatively low, especially for marine mammals and ecosystem structure, functions and processes.

In the sections that follow we look at the ecological impacts and opportunities in the different phases of an OWF; construction, operation, maintenance and decommissioning.

a. Construction phase

i. Impacts on biomass

In a recent study looking at the global impact of OWE, construction impacts were predominantly negative (52%) across the ecological subject groups compared with positive impacts (8%) with several species of fish (e.g. brill, cod, dab, plaice) and some species of birds (e.g. common guillemot, northern fulmar, redhead) showing strongly negative trends[11].

The best studied subject during the construction phase was the marine mammal, followed by birds and then fish. There is limited global peer-reviewed evidence of OWF construction effects on shellfish, benthic sediments, bats, humans, macro-invertebrates and effects occurring at the air-sea interface.

The construction phase of building an OWF is usually two to four years. In the Crown Estate's 'Guide to an Offshore Wind Farm' it states that the installation period for a 1 GW wind farm is typically between two and three years from the start of onshore works[12]. For Round 4 leasing the typical site sizes awarded are between 1.5 GW and 3 GW and in Round 5 the maximum capacity for the Project Development Areas is 1.5 GW. During the construction period the main impacts of OWFs relate to noise and habitat loss of the seabed. Construction impacts are particularly pronounced for fixed wind turbines which are built at sea and require significant foundations on the seabed, as opposed to anchor points.

For fixed turbine foundations the seabed needs preparation including dredging, trenching for cables and levelling. Monopile, jacket, or gravity-based foundations for fixed wind turbines involves drilling or piling into the seabed and this can include repeated hammering using hydraulic hammers. Scour protection involves placing rocks or concrete mats around the base of turbines to prevent seabed erosion and this creates noise from dumping rocks or using vibratory equipment. The construction of fixed OWFs involves heavy marine equipment (including pumps and winches) and support ships, so there are temporarily a lot of vessels with propellers and engine noises around.

Any type of fixed offshore wind pole will result in the direct loss of a small habitat area, as the section of the sea and the bottom occupied by such units will initially be unavailable for aquatic species. Cable-laying may displace benthic species and damage sensitive habitats[13].

Floating turbines are often assembled onshore and towed to site, reducing at-sea construction time and associated noise. As contact with the seabed is also limited to anchor points and mooring lines, these structures are also believed to be less invasive to marine habitats and wildlife and cover a much smaller footprint.

Birds

In a comprehensive review of ecological impacts, 32% of the findings reported high-moderate negative impacts with regards to birds[14]. During the construction phase pile driving and vessel traffic may create noise, movement and light that can disturb birds. Some species may display avoidance behaviour leading to the temporary loss of feeding or roosting grounds or increasing energy expenditure to find food or rest.

Bird species that are particularly sensitive to human activity or noise (like divers, sea ducks, and loons) are more likely to be affected. For example, the distribution and abundance of Loons changed substantially from the period before to the period after an OWF construction in the North Sea[15]. Abundance declined by 94% within the OWF + 1km zone and by 52% within the OWF + 10km zone. The study found that within three years of monitoring there was no evidence of the Loons returning, and they had settled in areas further from the OWFs.

During construction, heavy vessel traffic and activity zones may also cause migratory birds to reroute, potentially increasing energy expenditure[16]. Lighting on platforms and vessels can also attract birds, especially during night migrations or poor visibility conditions, increasing the risk of collision with structures or vessels and disorientation[17].

Careful siting during the planning phase to avoid key bird habitats can prevent a multitude of potential conflicts[18]. Other mitigation measures can include seasonal restrictions on construction (e.g. avoiding breeding/migration seasons) and the use of noise mitigation technologies (e.g. bubble curtains during piling to dampen sound transmission). DEFRA published new measures in January 2025 requiring that all offshore wind pile-driving activity in English waters should ‘demonstrate they have utilised best endeavours’ to apply noise-reduction methods: this includes primary (at-source) and secondary (propagation) mitigation. RWE deployed a bubble curtain for the first time in UK waters during the monopile foundation installation of the Sofia wind farm in April 2025.

Impacts on birds are likely to be short-term and temporary, especially if mitigation is employed. Despite low-level impacts on an individual windfarm basis, cumulative impacts of multiple offshore windfarm development have yet to be adequately determined[19]. Developing effective mechanisms to deliver such assessments remains an urgent requirement for the immediate future. There is a potential for cumulative negative effects, particularly for the most vulnerable species, as countries (including France and Italy) start building their first OWFs over the next decade.

Fish

In a comprehensive review of ecological impacts, 2% of the findings reported high-moderate negative impacts with regards to fish[20]. The magnitude of such impacts depends on the affected species and its level of vulnerability/sensitivity – species such as cod, brill, dab and plaice are found to be more affected during the construction phase[21].

Some species of fish (notably cod) are particularly sensitive to noise[22]. Noise-sensitive fish may avoid noisy areas which can lead to temporary habitat displacement and species relying on sound may experience reduced mating and feeding efficiency.

Construction can also disturb or remove benthic habitats, which are crucial for bottom-dwelling fish like brill, dab and plaice. Operational activities can increase turbidity, reducing visibility and clogging gills or affecting spawning grounds.

Mitigation measures can include the use of bubble curtains, acoustic deterrent devices, and seasonal work windows to avoid spawning periods. Silt curtains or controlled dredging methods can help with sediment control.

Mammals

For marine mammals, up to 7% of the findings referred to negative impacts, depending on the OWF development phase[23]. Impacts on marine mammals in the construction phase focus on pile driving, as it creates intense noise that can travel tens of km under water eliciting adverse behavioural responses that affect abundance and distribution[24]. Other construction activities such as jacket and turbine installation can also change acoustic habitats through increased vessel activity.

Harbour porpoises are known to be particularly sensitive to noise. In one study there was an 8–17% decline in porpoise occurrence observed in the impact block during pile driving and other construction activities[25]. Porpoise displacement was observed at up to 12km from pile driving activities and up to 4km from construction vessels. Though occurrence dropped, porpoises were still regularly detected in the construction area even during piling. This suggests partial displacement rather than full local exclusion.

A monitoring programme carried out on the seals of Scroby Sands OWF revealed a significant post-construction decline in harbour seal numbers, whereas the grey seal population significantly increased[26]. The authors suggest that extreme noise generated by piling operations was the main reason for seals displacement with effects extended to the mid-term. Similarly, tagged harbour seals showed 11–41% decrease in area usage around 500m from the turbine.

While offshore wind isn't the most serious threat to whales, it does pose potential risks due to increased ship traffic in the construction phase which can lead to ship strikes[27]. Pile driving when whales are nearby can also cause serious hearing damage – whales really rely on sound to communicate and navigate in areas where it's difficult to see more than 6 metres.

Mitigation measures for mammals can include seasonal restrictions during peak marine mammal presence or migration, bubble curtains and 'soft' starts to pile driving to allow animals to leave.

Invertebrates

There are fewer studies on the impacts on invertebrates during the construction phase but invertebrate species that live on or just below the ocean floor can be impacted by seabed disturbances during construction. Foundations and scour protection structures permanently replace soft-sediment habitats with hard substrates. While these may attract different species (e.g. mussels, barnacles), they eliminate native soft-bottom communities. Habitat loss can lead to the direct mortality of burrowing or non-moving species and sediment suspension can also affect filter feeders like bivalves. While invertebrates lack ears, they are not immune to the impacts of noise pollution, instead responding to vibration. Mitigation measures can include sediment control through silt screens or minimising the footprint of disturbance by precise installation and routing.

ii. Impact on natural processes

There can be increased turbidity in the construction stage of OWFs, particularly for fixed OWFs. The seabed disturbance during fixed OWF installation comes from piling, drilling, scour around foundations and burying cables, which all stir up sediment. For floating wind farms the main sources of turbidity are from anchor installation, but typically this disturbs the seabed to a lesser degree than fixed foundations.

At Hornsea OWF, environmental impact assessments identified temporary but significant turbidity plumes extending several km from construction sites, depending on the current strength and sediment type[28].

Increased turbidity from sediment resuspension can:

- Reduce light penetration, affecting photosynthetic organisms like seagrasses and benthic algae;
- Blanket filter feeders (e.g. mussels) and other benthic species;
- Disrupt the feeding behaviour and migration patterns of fish by reducing visibility;
- Clog the gills of certain fish or affect spawning grounds;
- Carry contaminants, like heavy metals, previously trapped in sediment.

Scheduling installation during calmer weather can reduce the impact of turbidity during the construction phase.

Whilst research on predator-prey interactions is currently very limited, there is some evidence that interactions are disrupted. Increased turbidity has been shown to reduce predation success for visual predators who may have reduced hunting efficiency (but research is not specific to OWFs)[29].

It would also be possible to surmise that the broad avoidance behaviour by various species identified above, reduces interactions at the construction site.

b. Operation phase

The operational phase is by far the longest impact phase for OWFs – the average lifespan of an OWF is around 25 years but this can be as much as 30-40. According to one study the operational phase impacts were more variable than the construction phase and could be either negative (32%) or positive (34%) depending on site specific conditions[30]. Approximately a quarter of all effects were classified as having no impact on subject groups (26%).

In the operational phase, OWFs are believed to provide many ecosystem services – the flow of benefits we (as a society) gain from the natural capital. These include:

- Provisioning services – ‘products’ such as enhanced fish stocks from artificial reef effects, no fishing (due to safety concerns) and aquaculture.
- Regulating services – services that regulate a natural process to society’s advantage, such as reduced carbon emissions, better air quality from reduced pollution, improved coastal water quality etc.
- Supporting services – helping other critical elements function e.g. organisms living on and around turbines playing a role in nutrient cycling, enhancing water quality and nutrient distribution.
- Cultural services – non-material benefits essential to our health and wellbeing such as a sense of place, recreation, spirituality, symbolic value and aesthetic quality.

While the subsequent effects operational OWFs have on ecosystem services still face policy limiting knowledge gaps, here we explore some of the documented provisioning, regulating and supporting services, as well as impacts on specific species.

i. Artificial reef effect

Fixed wind farms add vertical structure in otherwise flat seabed habitats. The turbine foundations and scour protection provides hard substrates in areas that may otherwise be sandy or muddy. These structures attract mussels, barnacles, anemones, and other sessile invertebrates, which in turn attract fish, crustaceans, and even marine mammals. This is known as the artificial reef effect.

The North Sea was once covered with hard substrates such as oyster beds, coarse peat banks and glacial erratics, providing habitat to a rich community of marine species[31]. Most of these habitats have since been destroyed by industrial fishing and today the seabed hosts a relatively poor species community[32]. However OWFs are changing this. Studies from the North Sea (including around UK wind farms like Thanet and Scroby Sands) have documented increased species richness and abundance near turbine bases compared to the adjacent sandy seafloor[33]. The red-listed tube-forming Ross worm (Sabellaria Spinulosa) has been observed establishing new colonies at turbine foundations here[34].

In 2019, The Crown Estate carried out a study into the pre-and-post-construction monitoring data for 76 OWFs, focusing on 4 key areas: fish ecology, benthic ecology, marine mammals, and birds[35]. Of the 45 wind farms for which comparable benthic data was available, it found that abundance of benthic species increased in 38% of them in the first 2 years following construction, compared to 15% where abundance decreased and 45% with neutral change.

A number of studies suggest it is possible for commercial fish species to benefit from OWF structures, potentially resulting in increased food provisioning benefits for society[36]. Positive impacts on enhanced abundance of populations were recorded for two commercially important species, cod and pouting, which were found to be more abundant on hard substrate[37].

The density of European plaice was also seen to increase after the construction of OWFs due to the increased food availability and/or fisheries exclusion effect[38]. OWFs offer a potential opportunity for exploring synergies and co-existence between maritime structures and nature, particularly if commercial fishing is also excluded from the areas. Wind farms have been known to act as refuges, with some species using the structures for shelter, spawning, nursery grounds or feeding[39]. Results from one study suggest that offshore windfarms may function as combined artificial reefs and fish aggregation devices for small demersal fish[40].

The artificial reef impact is believed to vary depending on the type of foundation used[41] and more research is needed to understand the optimum types to maximise the effect[42]. Positive effects are also thought to vary by species with some species showing an attraction to artificial reefs, but others not[43]. Modifying hard structures using ‘nature inclusive design’ (NID) methods is an active area of research. Biodiversity enhancement can be achieved by incorporating NID features into the OFW’s scour or cable protection layers[44].

Not all believe the artificial reef effect is real or positive. There is an ongoing aggregation vs. production debate that arose decades ago with regards to artificial offshore structures. Some argue that while areas appear to have higher biodiversity or biomass, the organisms are merely relocating rather than increasing in number[45]. Therefore it could just be a redistribution of existing life, rather than a net ecological gain.

Perhaps the biggest area of documented concern with artificial reefs is that increases in diversity may favour opportunistic or 'invasive' species, rather than threatened or rare ones. There is mounting evidence globally that artificial reef structures, both coastal and offshore, function as prime sites for colonisation by 'invasive' species as artificial reefs tend to favour hard-substrate specialists and generalist or opportunistic species[46]. Several groups of non-native species including mussels, oysters, algae, jellyfish, sea urchins and various macro-invertebrates (e.g. sea squirts, amphipods, crustaceans and tube-building worms) were recorded on fixed OWFs[47]. The marine splash midge, native to Australasian waters has also been observed at offshore wind farms in Denmark and along the Swedish Baltic coast, transported on the hulls of ships[48].

Colonisation by 'invasive' species can lead to:

- Competition with native species for space and resources.
- Displacement of local organisms.
- Alteration of local food webs.
- Habitat modification with invasive species altering sediment structures and water flow.
- Spreading of diseases which can impact local species.

There has been one long term-study on the colonisation and succession of offshore wind turbines by marine life looking at Belgian OWFs over a 10-year period[49]. The study showed three distinct succession stages: 1) Pioneer stage (2 years) – rapid colonisation by opportunistic species; 2) Intermediate stage (3-5 years) – higher diversity characterised by large numbers of suspension filter feeding invertebrates; 3) 'Climax' stage (6+ years) – lower diversity with turbines becoming co-dominated by plumose anemones and blue mussels. Most studies that suggest OWFs can become hotspots for biodiversity are short-term and refer only to the second stage of succession where diversity is high – they do not consider the following years where competitive species become dominant.

Few OWF studies have examined the potentially negative effects of invasive species that may attach on deep-water floating OWFs but a recent paper has shown that floating OWF structures can enable the establishment of benthic communities with a taxonomic composition similar to that of naturally occurring rocky intertidal habitats[50]. While floating OWFs will not have foundations, some anchoring systems and seabed cables will need scour protection and/or rock armouring. Floating foundations will vary in size and depth depending on the design used and will often present a greater 3-dimensional area for biofouling and reef formation in comparison with fixed bottom OWFs[51].

A growing body of literature would still suggest that the positives outweigh the negatives with artificial reefs, when developments are placed on homogenous benthic habitats. However other longer-term studies on the colonisation and succession of offshore wind turbines, both fixed and floating, remains an urgent requirement for the immediate future.

ii. De-facto marine protected areas (DFMPAs)

As referenced previously, one important effect of OWFs is that they can additionally act as marine preservation areas, when fishing and trawling is not allowed for safety reasons, creating DFMPAs. The reduction or absence of fishing around offshore wind farms creates reservations for species. The resulting proliferation is characterised by a higher concentration of marine species and their predators (birds, marine mammals, fish).

This benefit is particularly pronounced where bottom trawling is restricted. Bottom contact fishing gears are the most widespread anthropogenic sources of direct disturbance to the seabed, directly impacting organisms that live on or near the seafloor through physical damage from the trawl net or indirectly through the resuspension of seafloor sediments[52]. This leads to reductions in fauna biomass, numbers, and species richness[53]. In Lyme Bay, where bottom trawling has been banned since 2008, the seabed recovery and biodiversity improvements are well documented with much evidence of improved species diversity and species abundance in a previously highly exploited area[54] – there are now 430% more fish species and 370% more total fish inside the MPA area, than outside the boundaries, and the area has also experienced a 65% rise in 'functional richness' – a key measure of ecosystem diversity.

In another study, generalised linear modelling indicated that both density and biomass of California Sheephead were significantly higher inside a DFMPA[55]. Biomass of Ocean Whitefish was also significantly higher inside the DFMPA. Species richness and Shannon-Weaver diversity were not significantly higher inside the DFMPA, and overall fish community composition did not differ significantly between sites, however a longer trajectory of recovery may be required for other species – in Lyme Bay, for example, there was no change at all for the first 4 years.

DFMPAs can be good for nature and climate. 244 million tonnes of organic carbon is estimated to be in long-term stores across UK seas, with nearly all of this in the top 10cm of the UK seabed and at risk from disturbance[56]. Currently bottom trawl fishing is the leading cause of disturbance to this seabed store[57]. Research estimates that the sediment carbon released by bottom trawling globally is in the region of 1.47 billion tonnes per year and the UK is the fourth highest damaging country after China, Russia and Italy[58]. A recent study found 30% less organic carbon in deep-sea sediment continuously trawled for shrimp, compared to sediment where trawling had been banned for 2 months[59].

Fishing regulations vary from country to country; Belgium prohibits all fishing inside OWFs but Germany and the UK allow some types. Because of the complex mooring systems and cables in floating OWFs it seems most likely that all mobile gear will be excluded from them, meaning they may operate at a high level of protection, higher than many statutory partial MPAs created for the express purpose of nature conservation.

iii. Impacts on specific species

Birds

The majority of known impacts on birds during the operational phase of OWFs are negative, with a number of studies detecting reductions in abundance, biomass and diversity of birds around OWFs[60]. The impacts on birds in the operation phase tend to differ from those in the construction phase as they are typically chronic and longer-term, although this depends on factors such as wind farm location, turbine size, turbine layout, and species-specific behaviours. Species will differ greatly in their sensitivity to pressures, with different responses depending on their ecology (i.e. flight altitude, season, sex).

One of the most studied impacts is the risk of collision. Birds may collide with turbine blades, especially during poor visibility. Species most at risk include large, fast-flying birds (e.g. gulls, gannets and some raptors) and migratory species that pass through areas at night or in large numbers. The risk of collision between birds and turbines is seen as one of the key issues in the planning process for OWFs. Predictions of collision risk have led to projects either being withdrawn from the planning process or refused planning consent. Nature charities are currently calling for proposed floating OWFs in Scotland to be refused on the basis that they are predicted to kill tens of thousands of seabirds with many more losing their vital feeding areas[61].

The proposed Berwick Bank and Ossian OWFs are expected to reduce the Kittiwake population by up to 81%[62] at a time when around 70%[63] of seabird species are in decline in Scotland. For floating OWFs , the increased distance from land will likely reduce the number of species at risk, and the larger turbine spacing will likely reduce the risk of collision.

Some bird species may avoid or be displaced by OWFs. Displacement can be partial (reduced use) or total (abandonment of an area) and can lead to a loss of habitat and foraging grounds. OWFs can also act as a physical or psychological barriers to regular flight paths which is particularly relevant for migratory birds forced to detour, but also local commuting birds moving between feeding and nesting areas. Flying around turbines or seeking alternative feeding areas increases energy expenditure. Impact severity depends on the size and layout of the wind farm (e.g. Terns avoidance increases with turbine density[64]) and bird species flight behaviour (e.g. altitude, flexibility in route). Repeated or widespread displacement across multiple wind farms could have population-level consequences which is particularly a concern in regions with dense wind farm development (e.g. the North Sea).

The impact on birds is still an emerging area. A recent paper showed the impacts of OWE on soaring birds is greater than previously acknowledged with a study of Black Kites showing areas up to 674m away from turbines were less used than expected given their uplift potential[65]. Others show positive impacts for some species – one study showed the Lesser Black-Backed Gulls were using the turbines along the edge of the wind farm to roost, especially those situated closer to the colonies[66].

Mitigation measures are improving rapidly. These have previously included pre-construction surveys and modelling to avoid high-risk areas and the monitoring of bird behaviour and collision rates using observers. However this is increasingly technology-assisted using radars, camera systems, GPS transmitters, geofencing technology, and artificial intelligence (AI) to detect birds' movements in real-time, seeking to further reduce impact.

A recent AI-powered trial by Spoor, Vattenfall and the British Trust of Ornithology off the coast of Aberdeen proved promising for monitoring birds at offshore wind farms[67].

Scientists from the University of Glasgow have also just developed a new modelling tool which is believed to be the first of its kind to accurately predict space use of seabird colonies without requiring extensive satellite tracking data, which is often not available[68]. The researchers believe their new tool could be transformative for offshore wind farm planning, allowing it to protect wildlife while also safely building sources of renewable energy. Additionally, they say it could also be used to accurately predict the space use of other wildlife, including seals, bats and bees.

Shut down on Demand (the temporary stopping of wind turbine blades in response to the presence of at-risk species or a high number of birds) is also becoming increasingly sophisticated. Initially this relied on human observers but it is now increasingly technology-assisted.

Fish

Electromagnetic Fields (EMFs) emitted from high-voltage subsea cables may influence the behaviour of certain fish, particularly those that use electroreception (e.g. sharks, rays, sturgeons and lampreys) or those sensitive to noise. Long-term exposure could affect the behaviour or their feeding, indirectly impacting biomass dynamics of species populations.

The most comprehensive assessment on the effect of EMFs on fish was conducted in Denmark between 1999 and 2006[69]. The results on migration direction showed significant impacts on some species (e.g. Baltic Herring, Atlantic Herring, Common Eel, Atlantic Cod and Flounder) suggesting that the migration of some species across the cable route might be impaired.

The effects of EMFs are similar in both floating and fixed structures although floating farms might have longer cable runs to shore, which can expand EMF zones. A study has shown that deeper cables are preferable and as a cable's depth increased, the intensity of EMF's at the seabed surface decreased[70].

Mammals

This picture is mixed for marine mammals depending on the species, location and type of wind farm. In general, operational wind farms appear to have less severe impacts on mammals compared to construction. However, there are knowledge gaps about the long-term and cumulative effects, particularly as more and larger wind farms are built.

Harbour porpoises have been shown to display short-term avoidance behaviour during construction but slowly return during the operational phase[71] and the picture appears to be similar for seals[72] and dolphins[73]. Turbine arrays may act as barriers, altering movement patterns, especially for coastal or migratory species and EMFs from subsea cables can impact marine mammals sensitive to sound, like whales and dolphins. Secondary entanglement with lines and nets caught on mooring lines and cables may also be a moderate risk for large Baleen Whales[74].

Key challenges in understanding the impact on mammals include long-term behavioural monitoring, understanding species-specific hearing sensitivity and evaluating the cumulative impacts from multiple wind farms.

iv. Impact on other natural processes

Studies on fixed bottom OWFs have shown changes in wave height, current velocity, and turbulence within and downstream of farms have the potential to effect turbidity, light penetration, and primary productivity which can have impacts on pelagic and benthic ecosystems[75]. Changes to the atmosphere and ocean are tentatively identified as potentially having some ecosystem benefits.

A handful of studies have been done on the regulating service of carbon sequestration and storage and any impacts OWF may have on 'blue carbon' habitats[76]. Available results show that, once built, the presence of OWF may lead to strong positive changes in the flux of nutrients, organic matter, and carbon both inside and outside wind farms. One study suggests that total organic carbon flux to the sediment can be increased up to 50% in an area 5km around turbines, with a notable effect up to 30km away[77]. The long-term storage of carbon in the sediments around OWF is uncertain and it is likely that the storage may be of limited duration if the seafloor is disturbed due to the impacts of trawling or released following decommissioning.

Investigations using remote sensing indicate that wind farms also create an atmospheric wake, with reduced wind velocity and increased turbulence extending approximately 5-20 km downstream[78]. Current flows around OW infrastructure create a wake effect and wind flow over and around turbines arrays create a wind shear. This increases turbulence and vertical mixing in the water column that can enhance primary productivity with positive bottom-up effects for mid and high trophic level taxa[79]. Phytoplankton (which forms the base of the marine food web) from deeper water are brought to the surface and upwelled nutrient supply simulates phytoplankton growth in the surface waters[80]. The increased turbulence and differential flows aggregate prey which creates valuable foraging opportunities for planktivorous fish and larger mobile species[81]. Large mobile fauna are known to preferentially forage at these oceanic 'biodiversity hotspots' and may gain an energetic advantage by doing so[82]. Projects such as Predators and Prey Around Renewable Energy Developments (PrePARED) are currently researching the impacts on predators and prey distribution and behaviour around offshore wind farms, however it is still a field in its inception and the impacts of this ecosystem shift on wider natural processes is not yet well understood.

Although floating OWFs will use mooring systems, hydrodynamic models suggest that wind shear around the turbines will still create a substantial wake effect, with upwelling and downwelling downstream of the farm creating similar ecosystem impacts as those outlined for fixed bottom[83].

A small number of studies suggest OWFs can also impact sediment transport and downstream sedimentation[84] (with impacts as yet unknown), reduce extreme storm surges[85] and may even act as areas of low microplastics pollution[86]. However, evidence regarding how OWF affects various subject groups and their ability to remediate many waste products such as microplastics, excess nutrients and sewage, heavy metals, and many emerging or persistent pollutants is still scarce. OWFs are believed to affect water quality with chemical pollution. Chemicals can leach into the water from antifouling and anti-corrosion paints or coatings applied to structures. In addition, sacrificial anodes will mean a substantial quantity of aluminium per structure will enter the ecosystem.

SPOTLIGHT ON MITIGATION MEASURES: BEST PRACTICE

This table summarises all the mitigation measures that could be implemented throughout planning, construction and operation to reduce harmful impacts.

- Careful siting during the planning phase to avoid key habitats;
- Pre-construction surveys and modelling to avoid high-risk areas;
- The monitoring of bird behaviour and collision rates using observers;
- Seasonal restrictions on construction to avoid any breeding, migration or spawning seasons;
- The use of noise mitigation technologies including bubble curtains and acoustic deterrent devices, to dampen sound transmissions;
- 'Soft' starts to construction to allow animals to leave;
- Silt curtains, silt screens or controlled dredging methods to help with sediment control;
- The use of radars, camera systems, GPS transmitters, geofencing technology, and artificial intelligence to detect movement of species in real-time and/or accurately predict space use of species such as seabirds, seals and bats;
- Technology-assisted Shut down on Demand to temporarily stop the wind turbine blades in response to the presence of at-risk species or a high numbers of birds.

Table 1: Mitigation Measures

c. Maintenance

Service vessels for maintaining OWFs generate a largely unknown amount of noise to the surrounding ecosystem but it could be assumed regular vessel trips and underwater inspections may disturb marine life, particularly those most sensitive to noise. Maintenance activities can also introduce pollutants (e.g. lubricants, hydraulic fluids) into the marine environment if not well managed.

Operations on fixed-bottom structures are relatively simpler due to their closer proximity to shore, offering easier access for crews. In contrast, servicing floating wind farms is considerably more demanding, given their remote and harsh operating conditions. However, some major repairs can be executed by towing these platforms back to shore.

d. Decommissioning

So far, there is little published information available on the decommissioning of OWFs. The first generation of turbines come to their end-of-life expectancy in 2025 and research reveals that the UK must decommission approximately 300 and 1600 early-model offshore wind turbines by 2025 and 2030, respectively[87]. Current legislation and policy largely specify the complete removal of structures but it is not yet clear whether this will be the optimal solution for the environment and society.

Full removal would allow the natural seabed and marine habitats surrounding OWFs to regenerate, so long as the areas continued to remain protected from destructive fishing and other harmful activities. Full decommissioning would also prevent the long-term degradation of materials like coatings and cabling insulation leaking pollutants into the marine environment. Old or damaged infrastructure, if not removed, could potentially pose risks to ships while valuable metals could be recycled reducing the need for further resource extraction.

However removing the foundations and cables could lead to impacts akin to the construction phase of OWF development, creating significant noise pollution, disturbing sediments and harming marine life. The removal of foundations and cables could release contaminants that could harm benthic ecosystems and the benefits of the artificial reef effect and of OWFs on some natural processes, would also be lost.

With a lack of clear evidence currently, views can differ widely, often influenced by deeper philosophical viewpoints on what is ‘natural’ and how comfortable people are with man-made structures remaining in natural environments, even if they improve biodiversity. Researchers also acknowledge that today’s preferred decommissioning methods may become obsolete, and change depending on societal attitudes and ecological findings.

One paper, which synthesised 37 United Nations and Oslo-Paris Commissions (OSPAR) global and regional environmental targets, argued that abandonment (i.e. leaving OWFs as they are) would move environmental status most strongly towards environmental targets and the current international policy of removal, may not be the optimal solution for the environment and society[88].

Other experts propose leaving just parts of the OWF structures in place if they’ve become ecologically valuable from the artificial reef effect and their status as DFMPAs. This mirrors the Rigs to Reefs approach (the practice of converting decommissioned offshore oil and gas rigs into artificial reefs) including Eureka, California whose habitat is even more productive than some natural reefs[89]. Partial decommissioning can be controversial. Those opposed to it express concern about potentially setting a precedent and emphasise the ‘unnatural’ characteristics of the structures. Environmental groups argue that restoration of the marine environment prior to wind farm construction should be favoured over ‘artificial reefs of convenience’.

Another recent paper argues that while OWF structure can bring ecological benefits, important idiosyncrasies exist, with differences emerging between types of structure, habitat types, taxa and ecological metrics[90]. The paper found limited conclusive evidence that OWFs would provide significant ecological benefits if decommissioned as artificial reefs and concludes that decommissioning options aimed at repurposing OWFs into artificial reefs may not provide the intended benefits.

All of the above would suggest that decisions need to be made on a case-by-case basis in an inclusive way, where the intricacies of the specific wind farm are carefully assessed and deeper discussions are had on what types of ecosystems settled in OWFs are most ‘valuable’ or ‘desired’ and where ‘unnatural’ but improved states trump leaving sites in their previous , often degraded, states. One study[91] identified 10 decision-making criteria as being most significant, across three categories:

- Environmental – including biodiversity change, habitat alteration, carbon storage/release and nature protection potential;
- Economic – including cost of decommissioning, material recycling opportunities, commercial fishery implications, and liability costs;
- Social – including future access to the ocean, recreational opportunities, and political compatibility.

4. SOCIAL AND ECONOMIC IMPACTS AND OPPORTUNITIES

There has been much less research on the impacts of OWE on the human environment and local communities. The 'people' effects of OWF developments cover a range of social and economic impacts. 'Local' itself can also cover a range of spatial scales from adjacent coastal communities, to the whole of the UK. Much of the UK economic research to date has been at the UK level.

There can also be some scepticism about the importance of socio-economic impacts on host communities, especially when the OWF may be many km off the coast[92]. However, some OWFs are near the coast, and all OWFs have onshore components, including sub-stations, cabling and other local infrastructure and businesses.

a. Economic impacts and opportunities

i. Local/regional jobs and supply chain

OWFs can create jobs in construction, operations, and maintenance boosting local economies, however the actual employment picture is quite nuanced. A meta-analysis of literature on the socio-economic impacts of OWFs found limited evidence to acknowledge the employment benefits in the immediate local economy and social change in the community due to OWFs[93].

It has been identified that there is a significant amount of economic leakage from the UK economy in the capital expenditure/construction phase of OWFs, with only 30% of expenditure staying in the UK[94]. This is due to things such as imported components, foreign expertise in engineering, design and construction and lack of UK manufacturing capacity. However 75% of the operational and maintenance expenditure stage stays in the UK and it is also high for the development/planning stage (75%). Operation & maintenance employment numbers may be lower, especially compared with construction, but the varied activities are usually much more accessible to local people, and have a life of 20-25 years (sometimes longer with extensions), compared to the 2-4 in construction. More of the operational and maintenance expenditure stays in the UK because, unlike the construction phase, the phase relies heavily on local, ongoing services rather than specialised imported equipment. Work includes routine turbine inspections, port services and harbour operations, component replacement and repairs, monitoring and environmental compliance and onshore control room operations.

Whilst there is currently outsourcing of much of the offshore construction from local areas, there is more local potential with onshore construction work. In Aberdeen OWF the project performed well against economic impact predictions for onshore construction – roughly 60% of workers were from the inner area and the rest from the wider Scotland area. In contrast, the local and Scotland wide economic benefits from the major offshore construction were very limited, and much less than predicted. Of 500 construction workers employed at its peak only 10% were British and the Scottish contingent was very small[95].

The growth of floating OWFs may also be positive for local jobs as floating turbines can be assembled and pre-commissioned at port, then towed into position. This supports local fabrication yards, ports, logistics, and skilled labour, rather than relying on specialised foreign installation vessels. Floating wind also open up deeper waters, creating economic opportunities in new regions which may help spread the supply chain benefits across the UK rather than concentrating them in a few coastal areas. It has been suggested that new floating wind farms off Wales could create 5000 jobs and 1.4bn boost for economy[96]. In Scotland, the expansion of renewable energy projects, including offshore wind, is expected to bring up to £100 billion in investment and create over 18,000 jobs by 2040, surpassing historical investments like North Sea oil[97].

However floating OWF will not automatically reduce leakage, unless the UK invests in port infrastructure and develops a domestic supply chain ensuring Scottish, Welsh, and English ports and industries work together, not in competition.

It has been shown that the impacts of multiple OWF developments can be cumulative, and can be a catalyst for port development and other supply chain activities. For example, in the Humber, the group of wind farm developments over 10+ years has provided the area with the opportunity to establish a stronger foothold in the sector, secure inward investment and enable local businesses to access supply chain opportunities[98]. Strengthening the UK's offshore wind supply chain could contribute an additional £92 billion to the economy by 2040, highlighting the potential for growth in manufacturing and service sectors[99].

When done well there can also be new pathways to 'blue' jobs established. In the Humber, education and training initiatives include a new Masters programme in renewable energy at the University of Hull, an £11m investment in the University Technical College in Scunthorpe specialising in engineering and renewable energy and support in the regional growth fund for 380 local apprenticeships that include renewable energy. In Wales RWE partnered with Grŵp Llandrillo Menai to establish an award-winning turbine apprenticeship programme and have so far trained up over 100 apprentices to support the future of the industry.

ii. Fishers and the fishing industry

A new study has found that the majority of UK fishers feel their livelihoods are being threatened by the rapid expansion of OWFs, with impacts felt across all vessel sizes and fleet sectors[100]. Growth is creating significant spatial conflicts with the commercial fishing industry as both sectors compete for limited marine space and there is a loss of access to fishing grounds, especially for beam and demersal trawlers. Loss of access to traditional fishing areas can hurt livelihoods, particularly for small-scale operators.

The survey revealed that fishers across all fleet sectors were experiencing social, wellbeing, and economic impacts from offshore wind developments. While a small minority identified potential benefits, most fishers felt their fishing grounds and livelihoods were under threat.

The ecological impacts of offshore wind farms on commercial fish species and marine habitats were a significant concern[101]. Changes to wild fish stocks and commercial fisheries that ensue from OWF developments can be positive or negative depending on fisheries exclusion and displacement effects, physical energy effects (e.g. EMFs, waves and currents) and artificial reef effects. During the construction phase studies have shown decreases in cod, plaice, dab and sandeel landings but no evidence of sole and pouting landings being affected[102]. Conversely, observed landings of cod, pouting and other commercial sessile and mobile benthic macrofauna (e.g. blue mussels and brown crabs) have been shown to increase during the operation phase of OWF[103]. Another study found four times higher plaice abundances on the sandy patches of the scour protection[104].

Findings suggest that the 'spillover' effect could mitigate the negative impact of access loss on fishing activities, in a scenario of simulated closure of the area of the wind farm[105]. 'Spillover' has been defined as the 'net movement of individuals (fish) from MPAs (or DFMPAs) to the remaining fishing grounds'. There is plentiful evidence that MPAs lead to increased species spillover; however, whether spillover influences fish landings will depend on several factors, including the population status and movement patterns of target species, as well as the status of the fishery and behaviour of the fleet.

There is also some evidence that while MPAs can lead to increased species spillover, the effects will take a relatively long time period to be relevant for fisheries.

Offshore wind in the UK presents both opportunities and challenges for fishers depending on various factors like location, type of fishery, level of engagement in planning, and potential for economic diversification. (e.g. vessel charters, maintenance, and surveying). Where displacement of fisheries is taking place, then management options should be introduced to avoid, reduce or mitigate the environmental impacts of displacement.

b. Ocean literacy

Ocean literacy is the understanding of how the ocean influences individuals and how individuals, in turn, impact the ocean. Ocean literacy will be vital going forward as the UK strives to meet renewable energy and climate targets, necessitating a degree of understanding for infrastructure requirements while being aware of the effects on our oceans and the life that flourishes within, especially as the climate crisis continues to threaten these ecosystems.

On their own, OWFs don't guarantee a better understanding of ocean systems but if planned, communicated, and integrated into education and community engagement well, OWFs have a real ability to improve ocean literacy. They can highlight the ocean's role in renewable energy and climate solutions and people can begin to see the ocean as a source of sustainable energy.

Offshore wind projects are increasingly integrated into school and university curricula. This exposure promotes ocean-related careers and encourages deeper understanding of marine ecosystems, engineering, and climate science. Sofia OWF in the Tees valley has been actively involved in education and skills development, collaborating with local schools, universities, and service providers to raise awareness about offshore wind and its environmental impact[106]. Initiatives have included:

- A teacher training programme integrating offshore wind topics into school curricula, fostering a deeper understanding of renewable energy among students;
- Interactive events during British Science Week 2024, engaging hundreds of pupils in exploring the science behind wind energy;
- Work placements and scholarships providing students with real-world experience and financial support to pursue careers in sustainable energy;
- Development of teaching materials for primary and secondary schools, including videos and lesson plans on topics like renewable energy and the journey of electricity from wind farms to the national grid.

Blue Gem Wind's Erebus project in Wales has engaged students in naming floating wind platforms, such as 'Yellow Thunder' and 'Môr Egni', fostering a connection between young learners and renewable energy initiatives[107]. The project also offers educational packs and animated videos to help primary-level students understand climate change and the role of floating wind in addressing it.

Because OWFs are at sea, they're not easily accessible for hands-on education, unless supported by virtual tools, videos, or partnerships with local institutions. However, one of the largest OWFs in the UK, Rampion (off the coast of Brighton) offers unique educational guided cruises to observe the turbines and learn about renewable energy. These tours also highlight the environmental benefits of wind farms, including their role in creating marine sanctuaries by restricting certain fishing activities[108].

Ocean literacy efforts shouldn't just focus on energy and ignore broader ocean health issues (like biodiversity, pollution, or acidification), as this may lead to a shallow understanding of marine systems. Some OWFs also include citizen science programmes such as marine mammal monitoring, seabird surveys, and seabed habitat research.

Scroby Sands Offshore Wind Farm Information Centre is a research-led visual arts exhibition that looks at the relationship between offshore wind energy and Doggerland, the submerged landmass that used to connect the UK to mainland Europe. Merging fiction and non-fiction, the centre reflects on the artists perception of oceanic relationships that occur across time and the non-linear poetics of the sea[109].

Improved ocean literacy can also help the public understand OWF and the potential interactions – negative and positive – with sensitive and charismatic megafauna (e.g. seals and dolphins). Many individuals intrinsically value megafauna simply for knowing that they exist and are conserved, even if they never directly experience them[110]. Any harm that may befall them can hold a cultural importance to individuals[111].

Well-managed projects involve consultation with coastal communities, offering a platform to share knowledge about marine ecosystems and the impacts of human activity. If poorly managed, wind farms can lead to public mistrust or misinformation, which can actually undermine ocean literacy by spreading confusion or opposition rooted in misunderstanding. It's also important ocean literacy efforts consider how to reach inland or marginalised communities, so they don't unintentionally become excluded.

c. Seascape and visual amenity

There is initial evidence from a review that OWF's are perceived to reduce the visual amenity of seascapes and this may negatively impact on people's 'sense of place' or connection to the ocean[112]. The evidence found that people give special significance to the ocean and desire to avoid intruding upon it.

Visual impact is a key issue for public attitudes to OWF projects. A study of two offshore wind farms in Denmark showed that people with experience of OWFs located far from the shore had a more positive perception of their visual impacts than those with experience of OWFs located closer to the shore[113]. This could be a benefit for the emerging deeper-water floating OWFs, however other research has shown there is not a straightforward correlation between acceptance of wind turbines and their distance from the shore[114].

Research also demonstrates the importance of taking into consideration culturally meaningful aspects, which might have impacts on community attitudes and perceptions[115]. Although these are challenging to assess, they are crucial to understanding a community's response to an OWF where the cultural importance of seascape can play an important role in shaping responses[116]. The concept of Cultural Ecosystem Services explore the relationship with coastal communities and OWFs[117]; these services include 'non-material benefits which people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences'. For example, people coming to the sea wanting to enjoy an un-degraded coastal setting may feel an emotional loss of the open horizon and feel a sense of being limited.

d. Community empowerment

Communities can be empowered in many different ways through OWF development. This can be through education or training opportunities, however it can also involve:

- Direct financial support such as Community Benefit Funds – Approximately 75% of UK OWFs, in operation or under construction since 2010, have such funds, or plan to introduce them[118]. RWE state they have contributed over £21 million to neighbouring Welsh communities through their community funds tackling key issues[119];
- Opportunities for community ownership, profit share, and shares ownership – there are no examples for OW yet but they are attempting this for the first time in Scotland;
- Measures or initiatives to support the reduction of energy costs;
- The provision of new or improved local infrastructure;
- Sponsorship of organisations, sporting and cultural events;
- In-kind offers such as habitat management programmes.

It has been shown that early community engagement, to achieve a 'social license to operate', is crucial to lessen anxiety. This in turn can have a positive effect on the social impacts of any OWF development[120]. It is also important to ensure sustained engagement throughout the project lifetime, not just the pre-operation stage, in order to mitigate or avoid longer-term social impacts. Such engagement can contribute to equity and justice issues, with communities feeling engaged in decision-making about their future[121].

While Community Benefits Funds can have positive financial impacts, sometimes they are viewed as 'bribes'[122][123]. While not a bribe in a strict legal sense, payments can resemble bribes if the community view the compensation as an attempt to 'buy' their support, rather than a genuine benefit-sharing initiative.

Community Benefit Funds are more likely to be accepted by communities if the form of benefit aligns with local needs and concerns and if they are embedded in public engagement strategies (like education, consultation, deliberation)[124]. Bribery can also be avoided if schemes are designed strategically so they are fair and avoid eroding civic obligations. Researchers suggest that a well-designed Community Benefit Fund should[125]:

- Minimise self-interest. Schemes should avoid large up-front payments and focus on in-kind benefits;
- Respect the community. Employ and contract local staff, keep the community informed and respond transparently to complaints;
- Encourage community involvement. Big renewable projects should stack up on energy, environmental, economic and community grounds. Robust and genuine community consultation should be used when designing any benefit scheme;
- Ensure integrity. Development and implementation of any scheme should be genuine, transparent and accountable.

While there are no OW examples yet, terrestrially there have been many success stories of true community ownership too, which has been shown to generate a stable long-term revenue stream and create meaningful change.

Neilston was the first community-developer shared-ownership wind farm of its kind. Commissioned in 2013 near Neilston in East Renfrewshire, it comprised 4 turbines with a total capacity of 10MW. The project was a joint venture between the local community group Neilston Development Trust (NDT) and the commercial developer Carbon Free Developments (CFD). CFD handled the high-risk early phases which took the burden off NDT until the project was de-risked. Once planning consent was secured, NDT had the opportunity, to invest equity.

NDT raised £950,000 via loans from social-investment organisations to fund their stake, representing a 28% share of the wind farm. Over the projected lifetime of the wind farm, it was estimated to generate around £10–11 million in profit that could benefit the community. However in 2017, NDT sold its share to The Renewables Infrastructure Group. After the sale, NDT donated £2 million of the proceeds to a new fund, Neilston Windfarm Legacy (NWL), established to support community development projects — social, cultural, recreational, environmental, and economic initiatives. So while the community no longer owns part of the operating wind farm, the sale created a legacy fund intended to benefit Neilston for many years.

The project demonstrates that a community can realistically partner with a commercial developer. Through a community ownership model, communities — even small towns — can generate substantial income over time, supporting regeneration, social infrastructure, and long-term investments.

The Strategic Value of Community Benefits in Offshore Wind Development report highlights the growing importance for offshore wind proponents to build strong relationships with host communities and secure a social licence to operate, rooted in community trust and acceptance of a company and its activities[126]. This has the potential to come about through either well-designed Community Benefit Fund's or true community ownership.

For now, the community-ownership models remain rare for OW, so there is no clear guidance or best practice. Stromar is a floating offshore wind farm planned in Caithness, northern Scotland, with a capacity of 1GW. The developers explicitly say they intend 'to include genuine community involvement and ownership for the first time ever in an offshore wind development'. They are working with community ownership specialists Energy4All to explore how local Scottish communities might invest in and share benefits from the project.

5. IMPLICATIONS OF FINANCIAL MECHANISMS FOR MARINE REWILDING

a. Government financial mechanisms

Marine Net Gain (England)

In England, Marine Net Gain (MNG) is an emerging concept aimed at ensuring that all developments or activities in the marine environment (not exclusively OWFs) result in an improvement in marine biodiversity and ecosystem services, rather than just minimising harm or compensating for environmental damage. Marine Net Gain is at policy development stage and has seen some stakeholder support. It could see notable progress over the next 1–2 years as it moves towards further piloting and metrics finalisation.

MNG is a similar concept to Biodiversity Net Gain (BNG) used terrestrially. BNG became mandatory for major developments and small sites in early 2024. However, it is significantly more difficult to measure a "unit" of biodiversity in a moving, 3D marine environment than it is on land. It is a considerable technical challenge to create a "Marine Metric" that works.

BNG has drawn a range of criticisms that will need to be considered in the development of MNG. These include:

- That BNG can legitimise the destruction of habitats by allowing developers to compensate elsewhere, rather than avoiding harm;
- That gains are projected, not proven, and long-term monitoring and enforcement are often underfunded or patchy;
- That BNG credits / a biodiversity offset market may lead to speculative trading, land banking, and profit-seeking with little ecological oversight i.e. 'greenwashing'.

With regard to OWFs, there is a potential risk of "double counting" when it comes to turbine bases creating artificial reefs — in other words, claiming a benefit for a structure that was already going to be built anyway.

One of the key potential benefits of MNG for rewilding is the creation of a mandatory private market for restoration. If developers must prove a 10% biodiversity increase, rewilding projects (such as seagrass planting or kelp restoration) transition from being "charity-dependent" to being "commercially bankable." However, a potential risk is a focus on "quick-fix" habitats that score well on metrics rather than complex, slow-developing ecosystems.

Marine Net Benefit (Wales)

While England focuses on Marine Net Gain, Wales has developed a distinct concept known as Marine Net Benefit (MNB). This reflects the Welsh Government's focus on its unique legislative framework, specifically the Well-being of Future Generations (Wales) Act 2015 and the Environment (Wales) Act 2016.

England's Net Gain is heavily focused on measurable biodiversity units, while Wales's "Net Benefit" is more holistic. Instead of hitting a numerical target, MNB is tied to sustainable management of natural resources (SMNR), with the goal to improve the diversity, extent, condition, and connectivity of ecosystems.

The potential lack of a metric can lead to uncertainty for developers, who may not know exactly how much "benefit" is considered sufficient to secure a permit. Marine Net Benefit is still in the development and evidence-gathering phase.

One of the benefits for rewilding is a potentially holistic approach; if the policy progresses then it could be that a project in Wales is more likely to be approved if it demonstrates how rewilding will also benefit local fishing (economic), coastal protection (social), and maritime heritage (cultural). This encourages the large-scale connectivity between different types of marine habitats and social and economic benefits.

Marine Recovery Fund

The Marine Recovery Fund (MRF) is a UK government-backed and industry-funded initiative designed to support the rapid expansion of OWFs. The Marine Recovery Fund allows offshore wind developers to contribute to a government-managed pool that finances environmental compensation projects aimed at restoring and protecting marine habitats

Instead of requiring project-specific environmental mitigation, industry developers will make a single contribution to the fund. The MRF will fund strategic, pre-approved compensation measures such as creating or extending MPAs.

By consolidating developer contributions, the fund enables strategic, large-scale compensation for seabirds and marine ecosystems, fostering nature recovery while accelerating the approval of new wind farms. This system streamlines decision-making for developers, as pre-authorised environmental actions eliminate the need for protracted individual negotiations.

Proponents argue that a collective fund will allow for larger and seascape-level ecological projects with better outcomes than fragmented project-by-project approaches. However, some warn that the fund should not become an easy way for developers to bypass the requirement to first avoid and minimise environmental damage.

The MRF offers benefits for Rewilding in the potential landscape-scale impact. Instead of small, disconnected sites, the fund enables “strategic” rewilding, such as large-scale predator removal from multiple islands to protect seabirds.

The Fund was launched on 17 December 2025 and operates across both England and Wales, with the UK Government stating that “the launch of the fund will unblock 19 GW (of offshore wind capacity) in the immediate term”. Scotland is managing its own separate fund, with the Scottish Government publishing the formal analysis of its public consultation on December 18, 2025.

SMEEF

The Scottish Marine Environmental Enhancement Fund (SMEEF) is a Scottish conservation fund supporting marine and coastal restoration projects. Managed by NatureScot, Marine Scotland, and Crown Estate Scotland, SMEEF accepts public and private voluntary donations from those interested in the health of Scottish waters (especially from the OW industry) and strategically redistributes them to marine enhancement projects across the country. Since its inception SMEEF has awarded more than £4m to grantees working on projects that recover, restore or enhance the health of marine and coastal habitats and species.

There are four main funding categories:

- Seabed – work on seagrasses, native oysters and other seabed species and habitats;
- Coastal – work on saltmarshes, sand dunes and other coastal species and habitats;
- Wider Seas – work on marine mammals, fish and other mobile species;
- Seabirds – all work benefitting seabirds.

SMEEF is designed to be an effective, long running funding mechanism that will help bridge the nature finance gap.

SMEEF launched Scotland’s most ambitious seagrass planting programme on World Seagrass

Day 2025. The unique partnership between SMEEF and SSEN Distribution will see £2.4 million distributed to help restore nature in Scotland's seas. The partnership aims to plant 14 hectares of seagrass over the next three years, supporting both nature and coastal communities. To date grants have been awarded to four organisations spanning the length and breadth of Scotland.

By pooling voluntary contributions from marine users, SMEEF funds the "kickstarting" of rewilding—such as the Seagrass Meadows Scotland project—enabling local groups to restore their own shorelines without waiting for national legislative changes. SMEEF operates as a bridge between private donors and coastal communities with the consequence for rewilding of devolved, community-led restoration.

Marine Fund Cymru

The Marine Fund Cymru (MFC) is a new Welsh investment initiative being developed to support marine and coastal ecosystem resilience in Wales. Like SMEEF it aims to attract private and developer funding in Wales to put towards the long-term restoration, enhancement, and resilience of marine and coastal environments – supporting biodiversity, healthy ecosystems, and coastal communities. The creation of the fund has been a highly collaborative effort led by the Wales Coasts and Seas Partnership (CaSP Cymru). Key organisations involved in its design and governance include: Natural Resources Wales, The Crown Estate, WCVA, environmental NGOs, and the Welsh Government.

b. Other financial mechanisms

Private-sector partnerships

There are also a number of examples of bespoke partnerships between the private sector and NGOs.

WWT has teamed up with Aviva, the savings and insurance business, on a ground-breaking project to restore saltmarshes in the UK – unlocking the superpowers of wetlands[127]. Aviva, which has committed to invest £100m into nature-based solutions by 2030, has awarded WWT £21 million for the project, making it one of the largest of its kind in the UK. This pioneering partnership will enable them to restore and manage coastal saltmarsh at a landscape-scale and fund research into measuring and maximising its benefits.

Ørsted is partnering with Lincolnshire and Yorkshire Wildlife Trusts to help restore the biodiversity around the Humber Estuary, in Lincolnshire and Yorkshire[128].

The flagship project will invest more than £2.5m to restore parts of the Humber on an ambitious scale not seen before, through the planting of 3 hectares of saltmarsh and 4 hectares of seagrass, and the creation of a biogenic reef through the introduction of half a million native oysters. It will build on an ambitious programme of seagrass restoration work already underway between Orsted's Hornsea 4 project and Yorkshire Wildlife Trust. Ørsted has set an industry-leading ambition to deliver a net-positive impact on biodiversity across all the new energy projects it commissions from 2030 at the latest. DEFRA has commended this new pilot project as an example of how restoration of important marine habitats can work in practice and deliver multiple benefits.

6. THE ROLE OF OFFSHORE WIND IN A WILDER FUTURE – CONCLUSIONS

Marine rewilding is the large-scale restoration of marine ecosystems to the point where nature can take care of itself, and us, and accelerate the recovery of nearby marine areas. After centuries of human activity at sea, our ocean is irrevocably altered and only 13% of oceanic waters globally are now considered to be truly wild[129]. Just like the agriculture-formed countryside, we can no longer expect our ocean to be returned to a pristine, 100% wild state but there are reasons to be cautiously optimistic about the compatibility of offshore wind with marine rewilding.

Offshore wind could be part of a new kind of 'wild' – one that embraces the coexistence between nature and infrastructure. Rather than returning to a pristine past, a wilder future could be a resilient future where human ingenuity supports ecological recovery and addresses the urgent need for clean and renewable electricity generation.

As evidenced in the sections above, offshore wind isn't a silver bullet, but it could be a strategic ally in rewilding our seas if:

- Projects are **sited carefully** on homogenous benthic habitats, avoiding sensitive habitats and maximising ecological uplift;
- **Technological innovations** are harnessed to mitigate impacts during construction and operation, particularly on birds;
- **Nature-inclusive design** is embedded at the start of planning;
- **Monitoring and adaptive management** are prioritised to fill knowledge gaps, particularly from a whole-ecosystem perspective;
- **Policy mechanisms** like Marine Net Gain are used to channel investment into habitat restoration;
- **Early community engagement** is standard and there is sustained engagement throughout a wind farm lifetime and not just at the outset;
- **True community benefits and increased social value** are put at the centre of decision making;
- There is significant **investment in infrastructure** to develop a domestic supply chain and minimise economic leakage;
- Decommissioning is carried out on a **case-by-case** basis through an environmental, economic and social lens.

In the summer of 2025, the sea off the coast of the UK and Ireland experienced an unprecedented marine heatwave with temperatures increasing by as much as 4°C above average for the spring in some areas. These sorts of rises can cause widespread ecological impacts and highlight the importance of balancing the more negative impacts of expanding offshore wind, with the urgent need for renewable energy.

When designed and managed with nature in mind, offshore wind farms can create new habitats, displace destructive fishing practices, and support the regeneration of marine biodiversity. Safety exclusion zones can function as DFMPA's, offering refuge from bottom trawling and other pressures. Natural processes such as nutrient cycling and carbon sequestration can be enhanced, contributing to broader ecosystem resilience. There can also be new opportunities created in coastal economies and wider 'local' areas and ocean literacy can be improved.

While challenges will remain – including risks of invasive species, construction impacts, and uncertainties around decommissioning – these can be mitigated and monitored.

At its best, offshore wind could help Britain pioneer a new model of coexistence – where human infrastructure supports ecological recovery, where large-scale marine restoration creates new economies as well as new habitats, and where people feel empowered in shaping the seascapes of tomorrow.

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