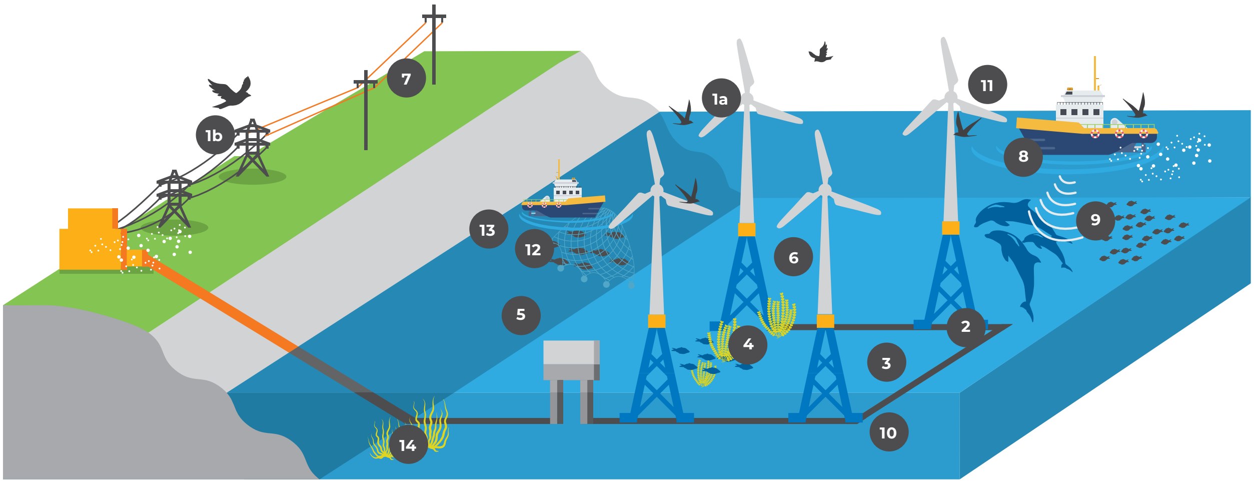
Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). *Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers.* Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.

Biodiversity impacts associated to off-shore wind power projects

The available scientific literature agrees on the key impacts of offshore wind: i) risk of collision mortality; ii) displacement due to disturbance (including noise impacts); iii) barrier effects (also including noise impacts); iv habitat loss; and v) indirect ecosystem-level effects. There is still much to understand on these five key impacts – but it is clear that that they must be considered carefully in all stages of offshore wind farm planning and development. The broad approach to undertaking an impact assessment for onshore wind energy is often equally relevant to offshore wind projects.

There is also evidence that in some circumstances offshore wind farms can have positive biodiversity impacts (case study 1), including introduction of new habitat, artificial reef effects and a fishery 'reserve effect' where marine fauna tend to aggregate due to the exclusion of fishing (Section 7.2.1). However, it should be noted that this may in turn lead to an increased attraction of foraging seabirds to the wind farm area. Table 6-1 summarises the key biodiversity impacts of offshore wind farm development, with selected references. For more detailed information, read the IUCN ***Mitigating biodiversity impacts associated with solar and wind energy development Guidelines for project developers***.

Figure 6.2 Potential impacts on biodiversity and the associated ecosystem services due to fixed-bottom offshore wind developments. Please see Table 6-1 for details on each impact type



1. Bird and bat collision with, a) wind turbines and b) onshore transmission lines
2. Seabed habitat loss, degradation and transformation
3. Hydrodynamic change
4. Habitat creation
5. Trophic cascades
6. Barrier effects or displacement effects due to presence of wind farm
7. Bird mortality through electrocution on associated onshore distribution lines
8. Mortality, injury and behavioural effects associated with vessels
9. Mortality, injury and behavioural effects associated with underwater noise
10. Behavioural effects associated with electromagnetic fields of subsea cables
11. Pollution (e.g. dust, light, solid/liquid waste)
12. Indirect impacts offsite due to increased economic activity and displaced activities, such as fishing
13. Associated ecosystem service impacts
14. Introduction of invasive alien species

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Table 6-1 Summary of the impacts of offshore wind farm development on biodiversity. The significance of particular potential impacts will be context-specific

No.	Impact type	Project stage	Description
1	**Bird and bat mortality from colliding with turbine blades and/or onshore transmission lines**	Operation	Birds flying in the turbine rotor swept zone are potentially at risk of collision and serious injury or death[1] (e.g. migratory birds passing through the wind farm area, or birds in the area to forage/hunt for prey). The percentage of time spent flying at collision risk height is key,[2] as is an understanding of species-specific avoidance behaviour.[3] Nocturnal migrant passerines are also at risk of collision, since they can be drawn to the nacelle lights.[4] Bats are also potentially at risk of collision and possibly barotrauma. While barotrauma (injury caused by sudden pressure changes around the moving blades) was initially hypothesised as a major source of bat mortality at onshore wind turbines,[5] there is little empirical evidence for this. Very little is known about the potential impacts of offshore wind farms on bats, although there are some empirical studies/observations. A good summary of the risk to bats from offshore wind farms is given in a recent review.[6] Bats have been shown to forage within wind farms and other offshore installations,[7] and studies have shown foraging at sea, for example between 2.2 km and 21.9 km[8] from the coast. Bats may also be attracted to offshore wind turbines, potentially by lighting.[9] While there is little information on flight altitudes of bats on migration, and on behaviour of bats at operational offshore wind farms,[10] there is sufficient evidence to suggest that many species migrate offshore and use islands, ships and other offshore structures as opportunistic/deliberate stopovers.[11] The characteristics of offshore migration of bats are well summarised in a recent review.[12] Onshore, there is potential for collisions with the (thin and hard to see) earth wire of transmission lines, which may lead to significant fatalities for some species such as bustards.[13]
2	**Seabed habitat loss, degradation and transformation (bottom-fixed turbines)**	Construction/ operation	Areas of benthic habitat may be lost completely under the foundation or degraded due to construction activity (causing sediment plumes and smothering), displacing benthic organisms permanently or temporarily. The total area lost is, however, generally tiny in relative terms.[14] There may also be impacts associated with lighting and vibration associated with construction, such as cable trenching remote-operated vehicles and foundation installation. Installation of foundations, scour protection and turbine towers can also have hydrodynamic effects that alter the demersal habitat or change water column conditions (see row no. 3).

1 Desholm & Kahlert (2005); R. W. Furness et al. (2013); Humphreys et al. (2015).
2 King (2019).
3 Skov et al. (2018).
4 BirdLife International (n.d.).
5 Baerwald et al. (2008).
6 Hüppop et al. (2019).
7 Ibid.
8 Sjollema et al. (2014).
9 Rydell & Wickman (2015).
10 Ahlén et al. (2007); Hüppop et al. (2019); Lagerveld et al. (2017).
11 Hüppop et al. (2019).
12 Ibid.
13 Mahood et al. (2017).
14 Perrow (2019).

3	**Hydrodynamic change (bottom-fixed turbines)**	Operation	The installation of foundations, scour protection and turbine towers can change hydrodynamic conditions, potentially affecting benthic communities and fish species.[15] Effects may be negative (e.g. scour around turbines, increased turbidity and smothering) or positive, through habitat creation (see row no. 4). Although impacts of wind turbines on the upper ocean is not yet well understood, turbines can disturb downwind wind fields by decreasing wind speed and increasing turbulence. Wind-wake effects can cause both upwelling and downwelling, potentially affecting an area 10–20 times larger than the wind farm itself, with possible knock-on ecosystem effects.[16]
4	**Habitat creation (including reef and refuge effects associated with bottom-fixed turbines)**	Operation	The new hard substrate introduced in turbine foundations, scour protection and turbine towers can create new habitat for colonisation by benthic organisms (case study 17). Turbine bases also often appear to provide a refuge for fish.[17] A typical offshore wind turbine can support up to four metric tonnes of shellfish,[18] which might be expected to attract a range of other organisms to the wind farm area. The initial colonisation of species within lower trophic levels is quickly followed by larger invertebrates, such as crabs and lobsters and small fish, thereby attracting larger predatory fish.[19] Such alteration of the local biodiversity status could have a positive ecosystem services influence in terms of biodiversity, tourism and fisheries effects.[20] The exclusion of fisheries from the offshore wind farm area, which may or may not be regulatory – depending on the jurisdiction – can offer refuge and shelter for both benthic communities and fish. A review of offshore wind power for marine conservation concluded that offshore wind farms can be at least as effective as existing marine protected areas in terms of creating refuges for benthic habitats, benthos, fish and marine mammals.[21]
5	**Trophic cascades**	Operation	Changes in benthic habitat and hydrodynamic conditions, and new habitat creation associated with the offshore wind farm (see row no. 4), have the potential to affect species abundance and community composition, and therefore affect predator-prey dynamics around an operational offshore wind farm. This is likely to be a greater risk to fixed-bottom compared to floating turbines. Evidence shows that important changes to the fish community structure and the trophic interactions within the local marine ecosystem occur where fish are attracted to the wind farm (in turn attracting foraging birds and marine mammals to the wind farm area). [22] A Dutch study found more porpoise activity in the operational wind farm area in reference areas outside the wind farm, which is most likely linked to the increased food availability, exclusion of fisheries and reduced vessel traffic.[23] A study on wind farms in the Bay of Seine, France showed that higher trophic levels including some fish, marine mammals and seabirds responded positively to the aggregation of biomass on wind farm structures, and that total ecosystem activity increased after construction of the wind farm,[24] although these wind farm effects on the coastal trophic web are considered as limited. The effect of trophic cascades may become more apparent with long-term monitoring.

15 ICES (2012).
16 Boström et al. (2019).
17 Bergström et al. (2013); Langhamer (2012); Wilhelmsson et al. (2010).
18 Emerging Technology (2017).
19 Gill & Wilhelmsson (2019).
20 Soukissian et al. (2017).
21 Hammar et al. (2015).
22 Gill & Wilhelmsson (2019).
23 Lindeboom et al. (2011).
24 Raoux et al. (2017).

6	**Barrier effects or displacement effects due to presence of wind farm (bottom-fixed turbines)**	Construction/ operation	Barrier and displacement effects[25] arise where the wind farm presents an obstacle to regular movements to and from breeding colonies or migration routes, or deters species (birds, marine mammals, turtles and fish) from regular use of the wind farm area. Whilst there are few supporting empirical studies, the variation in observed displacement levels for different seabird species is hypothesised to be due to several factors, including habitat quality, prey distribution and wind farm location relative to the colony/feeding grounds.[26] Models show that red-throated divers (*Gavia stellate*), for example, may experience displacement effects up to 15 km from the wind farm.[27] Telemetry studies of guillemots (*Uria aalge*) also show avoidance behaviour during the breeding season.[28] The effect of barrier and displacement is hard to quantify (manifested through impacts on daily time and energy budgets, which may ultimately reduce demographic fitness), and the two may be difficult to differentiate.[29] The impact on birds may vary spatiotemporally due to habituation and cumulative effect of other wind farms.[30] Conversely, some foraging seabirds have been noted to be attracted to wind farm areas[31] (and see habitat creation and trophic cascades above in this table). Bats' response to turbines differs across species and locations. Very little is known about the potential impacts of offshore wind farms on bats, although there are some empirical studies/observations (see row no.1).
7	**Bird and bat mortality through electrocution on associated onshore distribution lines**	Operation	With respect to the onshore facilities associated with an offshore wind farm, electrocution rates on the pylons of low- or medium-voltage lines can be high and disproportionately affect some species that use low-voltage pylons as perches when hunting or nesting. Electrocutions may be partially responsible for the decline of some long-lived species, and are rarely significant on high-voltage transmission lines.[32] In developed countries with better-developed electricity/grid facilities, offshore wind developments are likely to connect into existing transmission/ distribution facilities. However, in emerging markets, the onshore grid facilities may need to be constructed from scratch. There is limited evidence of risks to bats, although electrocution of large bat species, particularly fruit bats, has been identified as an issue associated with distribution lines.[33]
8	**Mortality, injury and behavioural effects associated with vessels**	Site characterisation/ construction/ operation/ decommissioning	Marine mammal collision with vessels is a known risk – most reports involve large whales, but all species can be affected.[34] Marine mammals in the wind farm area are potentially at risk of vessel strike during the site characterisation phase, and throughout wind farm construction, maintenance and decommissioning, leading to injury or mortality. They may also be subject to behavioural and harassment impacts associated with vessel activity during these phases.[35] Any marine mammal using the area is potentially at risk. A study using encounter rate theory has shown that for whales, the overall expected relative mortality is approximately 30% lower where vessel speed is regulated.[36] Turtle species are also vulnerable to vessel strike when they surface to breath, bask or forage at/near the surface.[37] Adult turtles appear to be at increased risk during breeding and nesting season.[38]

25 Humphreys et al. (2015); Masden et al. (2009); Vallejo et al. (2017).

26 Cook et al. (2014); Furness & Wade (2012); Furness et al. (2013); Vanermen & Stienen (2019).

27 Dorsch et al. (2016).

28 Peschko et al. (2020).

29 Humphreys et al. (2015).

30 Drewitt & Langston (2006).

31 Cook et al. (2014); Skov et al. (2018); Walls et al. (2013); Welcker & Nehls (2016).

32 Angelov et al. (2013); Dixon et al. (2017).

33 Kundu et al. (2019); O'Shea et al. (2016); Tella et al. (2020).

34 Cates et al. (2017).

35 In the U.S., incidental take authorizations may be issued by NOAA Fisheries for activities that could result in the harassment of marine mammals. The effects of these activities are typically analyzed pursuant to the National Environmental Policy Act of 1969 (as amended) and, where endangered or threatened marine mammals may be affected, the Endangered Species Act of 1973 (as amended).

36 Martin et al. (2016).

37 NOAA Fisheries (2017).

38 Ibid.

9	**Mortality, injury and behavioural effects associated with underwater noise**	Site characterisation/ construction/ decommissioning	Marine mammals,[39] turtles[40] and fish[41] are potentially at risk of sub-lethal exposure to underwater noise arising from offshore wind farm site characterisation (impulsive noise from seismic survey airguns), construction (impulsive noise from piling operations), operation (continuous noise associated with operational wind turbines) and vessel activity (continuous noise from engines and propellers)[42,43,44] and from decommissioning activities (cutting and drilling to remove/cut off subsea structures). As sound propagates through seawater it loses energy, which happens more quickly at high frequencies but can still be detected tens of kilometres away.[45] Four zones of noise influence are recognised:[46] i) zone of audibility (where animals can detect sound); ii) zone of responsiveness (where animals react behaviourally or physiologically); iii) zone of masking (where noise is strong enough to interfere with detection of other sounds for communication or echolocation); and iv) zone of hearing loss (near enough to the source that received sound level can cause tissue damage or hearing loss). The available data show that all marine mammals have a fundamentally mammalian ear (resembling land mammal inner ears), which has adapted in the marine environment to develop broader hearing ranges.[47] Impacts are best studied for harbour porpoise (*Phocoena phocoena*) and harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*) and bottlenose dolphin (*Tursiops truncatus*).[48,49] These are the more abundant species of shallow shelf seas in Europe, where there is a concentration of offshore wind farm activity. A number of studies have shown disturbance and partial displacement of harbour porpoises up to distances of 20 km during piling activities, reversible within 1–3 days.[50] Hearing capabilities in fish vary substantially between species. One method to understand their sensitivity is based on differences in their anatomy.[51] Some are highly sensitive such as Clupeids (herrings)[52] and Gadoids (cods).[53] Most other species detect sound through particle motion.[54] The current understanding of the impact of anthropogenic underwater sounds on fish is limited by large gaps in knowledge of effects of sound on fishes.[55] However, there is evidence that especially intense sounds affect sound detection and behaviour, and potentially result in injury and death.[56] Whilst there is significant data on hearing in pinnipeds, cetaceans and fish, far less in known about possible impacts on hearing in turtles.[57]

39 Bailey et al (2010).
40 Dow Piniak et al. (2012).
41 Sparling et al. (2017); Thomsen et al. (2006).
42 Hastie et al. (2019).
43 Popper & Hawkins (2019).
44 Weilgart (2018).
45 Nehls et al. (2019).
46 Ibid.
47 NRC (2003).
48 Hastie et al. (2015).
49 Bailey et al. (2010); Nehls et al. (2019).
50 Nehls et al. (2019).
51 Popper et al. (2014).
52 Popper (2000).
53 Hawkins & Popper (2017).
54 Ibid.
55 Hawkins et al. (2015).
56 Hawkins & Popper (2018).
57 Ketten (2017).

10	**Electromagnetic fields of subsea power cables: behavioural effects**	Operation	Studies suggest fish and other benthic organisms could be influenced behaviourally and physiologically by electromagnetic fields (EMF) associated with wind farm cables. These effects depend on type of cable, power, type of current and burial depth. To date, this potential impact is relatively understudied.[58] Electromagnetic-sensitive species come from across many taxa, but there is a paucity of knowledge on a restricted number of species, on how they respond to anthropogenic electric or magnetic fields compared with natural bioelectric/geomagnetic fields.[59] Sensitive species include those with a significant migratory phase, including salmonids and eels, for which EMF may constitute a potential barrier to movement[60] and those with electroreceptors such as sharks, rays, sturgeons and lampreys.[61]
11	**Pollution (dust, light, solid/liquid waste)**	Site characterisation/ construction/ operation/ decommissioning	The site characterisation phase may involve light pollution effects associated with survey vessels (as well as noise, as already noted). Construction, operation and decommissioning can lead to water, dust, waste and light pollution impacts. Examples specific to wind developments are limited, but studies suggest birds and bats may be attracted to lighting at offshore installations.[62,63] Attraction to lighting combined with poor weather conditions (poor visibility) can lead to birds flying at lower altitudes, which can dramatically increase collision risk with anthropogenic structures.[64]
12	**Indirect impacts**	Construction/ operation/ decommissioning	There is potential for the displacement of fishing activities and other marine traffic (shipping routes and recreational vessels), arising from offshore wind farm presence, leading to pressures on biodiversity and ecosystem services (see row no. 13) outside the wind farm area. This can increase pressure on sensitive areas elsewhere, as is reported for Taiwan.[65] Displacement of fishing effort, combined with the habitat created within the wind farm area (see row no. 4), can result in a 'refuge' effect, where fish and benthic communities proliferate in the wind farm area, in the absence of/reduction in fishing activity, with subsequent attraction of predator/foraging species. In areas of weaker governance, such as emerging markets and less developed areas, offshore wind farm construction may also give rise to in-migration of the associated workforce and their families, with induced access to coastal areas via new/improved roads: new human settlements in previously remote areas resulting in degradation of natural habitats; unsustainable natural resource use; and illegal or unsustainable hunting, fishing or harvest of vulnerable species. For onshore facilities, indirect impacts could result from road construction and improvement associated with substations, grid connection, access to the coastal cable landfall site, and any expansion/ enhancement/increased use of ports and harbours. These can increase settlement and induce access to formerly remote areas.

58 Bergström et al. (2013); Öhman et al. (2007); Taormina et al. (2018); Wilhelmsson et al. (2010).

59 Perrow (2019).

60 Gill & Wilhelmsson (2019).

61 Ibid.

62 May et al. (2017); Rebke et al. (2019).

63 BirdLife International (n.d.b); Rydell & Wickman (2015).

64 Hüppop et al. (2019).

65 Zhang et al. (2017).

13	**Associated ecosystem service impacts**	Construction/ operation/ decommissioning	In the offshore environment, construction of a wind farm could lead to loss of important fishing areas and displacement of fishing effort. Some fishing activities may be displaced due to safety or gear limitations (e.g. dredging displaced because of the wind farm structures), but some may continue (e.g. pot fisheries).[66] A study in the German exclusive economic zone (EEZ) of the North Sea indicated that the international gillnet fishery could lose up to 50% in landings when offshore wind farm areas are closed entirely for fisheries.[67] In Korea, a study into the possibility of fishing in an offshore wind farm area, based on the risk associated with the presence of turbines and cables, found the highest risk methods to be stow net, anchovy drag net, otter trawl, Danish seine and bottom pair trawl. Lowest risk methods were single-line fishing, jigging and anchovy lift net.[68] The exclusion of fisheries from the offshore wind farm area may or may not be regulatory – depending on the jurisdiction. In the decommissioning stage, not all structures will necessarily be completely removed – some may be left in place if they have become heavily colonised and support an important ecosystem – thus some fishing activity may still not be possible after the end of the wind farm life for safety reasons. In the nearshore and coastal areas, and in the vicinity of the onshore infrastructure required (substation/grid connection, ports, harbours), there could also be a loss of cultural values, or sense of place/belonging arising from wind farm construction/presence. In some areas, particularly coastal, there might also be tourism, aesthetic-related impacts. These associated ecosystem service impacts could have adverse effects on the well-being of local people. However, it is not yet well understood in relation to offshore wind farm development.
14	**Introduction of invasive alien species**	Site characterisation/ construction/ operation/ decommissioning	Movement of equipment, people or components may facilitate the introduction of invasive alien species (IAS), for example via movement of vessels on hulls and in ballast water and other equipment.[69] The hard substrate used for foundations may provide habitat for invasive species, allowing newly introduced species to become established in the area, or existing populations of invasive species to expand.[70]

Note: The numbering corresponds to the illustration in Figure 6.2.

66 Dannheim et al. (2019).
67 Stelzenmüller et al. (2016).
68 Jung et al. (2019); Tonk & Rozemeijer (2019).
69 Geburzi & McCarthy (2018); Iacarella et al. (2019).
70 De Mesel et al. (2015); Perrow (2019).