# CHAPTER 6

# KEY ISSUES FOR SEA IN THE WIND POWER SUB-SECTOR

Onshore and offshore wind power is addressed separately in this Chapter in sections 6.3 and 6.4.

## 6.1 WHY SEA IS IMPORTANT TO THE WIND POWER SUB-SECTOR

SEA can provide critical information to support better decision-making for wind energy planning and development, including identifying where there may be implications for PPPs to adequately address significant environmental and/or socio-economic risks and impacts. This information can be particularly important to identify and assess the scale and significance of possible cumulative impacts of multiple wind energy schemes/developments whether alone or in combination with other renewable energy technologies (e.g., solar).

The SEA process will:

- Identify and focus on key environmental and socio-economic issues and risks and the concerns of likely affected stakeholders, including local communities, marginalised groups and indigenous peoples. Major issues are discussed in detail in sections 6.4 and 6.5 and are summarised in Tables 6.2 and 6.3.
- Identify what changes or additions are required to PPPs governing wind power development to address these risks.
- Make subsequent project-level EIAs more efficient and cheaper by addressing the big picture and upstream, downstream, and cumulative potential impacts, identifying the particular issues that enabling individual EIAs should focus on in more (site-specific) detail. This may also include spatial planning recommendations for optimal siting of wind power projects to minimize these risks and impacts.
- Engage stakeholders – including communities, marginalised groups and indigenous peoples which can be particularly affected by wind power developments - to be informed of proposed or possible policy options or plans and enable them to provide their perspectives and present their concerns. This will enable key issues to be identified and verified, help build understanding and support for wind power development, and avoid future misunderstanding and possible conflicts.

The steps and methodologies available for use in SEA are common to all SEAs, whatever they are focused on, and reflect internationally accepted standards of good practice. They are discussed in detail in Chapters 1 and 3 and are therefore not repeated in this chapter.

## 6.2 EXISTING SEA GUIDANCE/GUIDELINES FOR THE WIND POWER SUB-SECTOR

An international survey of existing SEA guidelines conducted for the IAIA was unable to identify any specifically focused on the wind power sub-sector; but a number of guidelines and papers address project-level IA for wind power developments[1]. New guidance on key environmental factors for offshore windfarm environmental impact assessment has recently been released by the Australian government[2].

## 6.3 INSTALLED WIND POWER CAPACITY

In 2021, global installed wind capacity was 837 GW (780 GW onshore; 57 GW offshore) (Table 6.1).

[1] e.g. Durning and Broderick M. (2018); EU (2011); GIZ (2018); GP WIND (undated); MESP (2010); MSEA (2013); Phylip-Jones and Fischer (2013); and RVO (2022)
[2] DCCEEW (2023).

## 6.4 ONSHORE WIND POWER GENERATION

### *6.4.1 Onshore installation types*

Onshore wind turbines capture energy from the wind and produce electricity using long, rotating blades that drive a generator located at the top of the tower behind the blades. The longer the propellers, the more kinetic energy they can catch and 'harvest' from the wind. The current tendency in wind power development is for towers to become increasingly taller and blades to be longer to increase power generation of individual units.

Onshore wind is a developed technology, present in 115 countries around the world. The top 10 countries with the largest wind energy capacity in 2021 were China, US, Germany, India, Spain, United Kingdom, Brazil, France, Canada, and Italy[3].

Wind turbines can be tall, as much as 300 meters in height, to make the most use of available wind. To maximize power generating potential, wind farms are usually located where topography and weather patterns offer the highest potential for significant natural wind. They are often on agricultural land or on hilltops and mountains, sometimes coexisting with other land uses such as livestock grazing or cropping areas. The number of turbines at wind farm sites varies depending on the net total output required for each installation.

Land used for large-scale agricultural production (e.g., for livestock or cropping) can often be readily combined with wind turbines. In general, a relatively small portion of the productive land is utilized for a wind farm's operation, e.g., turbine siting, access roads, and other related assets such as transmission line easements, electrical substations, transformers, and meteorological masts. The landowner usually continues agricultural activities on the remaining land. Typically, there is disruption during the construction phase but only minimal disruption when the wind farm is operational, e.g., for access and maintenance[4.]

A wind turbine comprises four main parts: the base, tower, generator, and blades (or propellers). Each turbine is connected by an array of cables that connect to a substation before electricity is fed into the electricity grid. Construction of transmission lines and substations are required.

Construction activities for wind turbines typically include land clearing and levelling for site preparation and access routes; excavation, blasting and filling; transportation of supply materials and fuels; building foundations involving excavations and placement of concrete; using cranes to unload and install equipment; construction and installation of associated infrastructure; installation of overhead conductors or cable routes (above-ground and underground); and commissioning of new equipment.

As the wind turbine components (turbine blades) are large, special purpose vehicles are often used to transport them to a site. This can be a challenging in areas of steep terrain and in areas where the existing road or access infrastructure is less developed. Where access is limited, new roads and road upgrades may be required and need to be undertaken before construction.

Box 6.1 provides examples of some recent onshore wind farm projects in Southeast Asia.

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3 https://www.power-technology.com/features/wind-energy-by-country/

4 Australian Energy Infrastructure Commissioner (AEIC). Host Landholder Matters. AEIC website (see: www.aeic.gov.au/observations-and-recommendations/chapter-1-host-landowner-negotiations)

**Table 6.1: Installed wind energy capacity in 2021.** Source: GWEC (2022)

| **Continent/country** | **Installed capacity (MW)** | **Continent/country** | **Installed capacity (MW)** |
|---|---|---|---|
| **ONSHORE** | | **OFFSHORE** | |
| ***Total onshore*** | ***780,275*** | ***Total offshore*** | ***57,176*** |
| ***Americas*** | ***188,233*** | ***Europe*** | ***28,154*** |
| USA | 134,354 | United Kingdom | 12,522 |
| Canada | 14,255 | Germany | 7,728 |
| Brazil | 21,580 | Belgium | 2,262 |
| Mexico | 7,262 | Denmark | 2,308 |
| Argentina | 3,287 | Netherlands | 3,003 |
| Chile | 3,444 | Others Europe | 331 |
| Other Americas | 4,051 | ***Asia-Pacific*** | ***28,980*** |
| ***Africa/Middle East*** | ***9,085*** | China | 27,680 |
| Egypt | 1,702 | South Korea | 133 |
| Kenya | 440 | Other APAC | 1.167 |
| South Africa | 3,163 | ***Americas*** | ***42*** |
| Other Africa | 3,780 | USA | 42 |
| ***Asia-Pacific*** | ***375,161*** | | |
| China | 310,629 | | |
| India | 40,084 | | |
| Australia | 9,041 | | |
| Pakistan | 1,516 | | |
| Japan | 4,523 | | |
| South Korea | 1,579 | | |
| Vietnam | 3,231 | | |
| Philippines | 427 | | |
| Thailand | 15,54 | | |
| Other APAC | 2,577 | | |
| ***Europe*** | ***207,796*** | | |
| Germany | 56,814 | | |
| France | 19,131 | | |
| Sweden | 11,915 | | |
| United Kingdom | 14,064 | | |
| Turkey | 10,681 | | |
| Other Europe | 95,191 | | |

**Box 6.1: Recent onshore wind farm projects in Southeast Asia**

Sidrap Wind Farm, Indonesia. The 75 megawatt (MW) wind farm is in the Sidrap region in South Sulawesi. The project is Indonesia's first utility-scale wind farm and began providing power to the Southern Sulawesi grid in March 2018. The project uses 30 2.5 MW turbines. (Photo).

***Figure 6.1: The completed Sidrap Wind farm, Indonesia. Source***

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Tolo 1 Wind Farm, Indonesia. The 72 MW wind farm is located in the Jeneponto Regency area of South Sulawesi. Commissioned in 2019, it has 20 wind turbines, with each tower 134m high using 64m long blades (Photo).

**Figure 6.2: Construction of a wind turbine for the Tolo 1 Wind farm, Indonesia**

*Source: www.venaenergy.com [permission given]*

La Hoa and Hoa Dong Wind farms, Mekong Delta, Viet Nam. Currently under construction, each of the 30 MW projects are in Vinh Chau and Soc Trang, Viet Nam. Each project utilizes 8 turbines on 162-meter tall towers. Both projects include a 110 kilovolt substation and transmission line, and a total of over 17 kilometers of transmission lines.

Hanuman Wind Complex, Chaiyaphum, Thailand. The 260 MW complex consisting of five wind parks with 103 turbines is in the northeastern province of Chaiyaphum. It started operations in 2019.

### 6.4.2 Key environmental issues and impacts for onshore wind power

During scoping for a SEA, key issues regarding wind power development should be identified. They will be used to focus the SEA on the most important issues and to help develop environmental and social quality objectives (ESQOs) – that address these issues - to be used during the main assessment stage. The key issues will be identified by reviewing relevant documents (e.g. EIA and special subject reports, environmental/social profiles, sector and inter-sector strategies, donor documents, academic papers, other wind power development applications, wind profiles and meteorological data, etc.), interviews with key informants and during stakeholder consultations at national to local levels. Many of the issues will be well known as a result of implementing other wind power development projects.

At the individual project-level these issues will be the focus of an EIA which should recommend how to manage or mitigate project impacts associated with these issues that might be likely to arise. Ideally before individual wind projects are approved, the implementation of a policy, plan or programme (PPP) for the wind power sub-sector should be completed. This will involve the assessment of multiple projects, schemes and activities, some directly concerned with the construction and operation of sites and facilities; others linked to associated infrastructure (e.g. transmission lines, access roads). Thus, there is a risk that the impacts of individual developments/projects may become highly significant as they become cumulative. A SEA should be focus on the potential for such cumulative impacts and make recommendations for addressing them. This may include recommending thresholds for particular factors that should not be breached by an individual project (and which should be addressed by a project-level EIA). Where the risks of cumulative impacts are extremely high, this might provide the basis for the SEA report to recommend an alternative to the PPP or components of it. Often, the timing of individual wind power applications and overarching SEA planning is not synchronized, and SEA may have to “catch-up” to the pace of individual projects rather than providing upstream (pre-project) guidance as to how wind power development should proceed.

Table 6.2 summarises the key environmental and socio-concerns concerns likely to be associated with wind power development.

Wind energy turbines can have both direct and indirect adverse impacts on the onshore environment during construction, operation and maintenance, and decommissioning.

***Habitats and biodiversity***

The IFC has identified potential risks to habitats and biodiversity due to onshore wind power development[5] :

- Permanent habitat loss due to land clearing for temporary project components such as site huts and worker’s accommodation, and for permanent components such as roads, turbine foundations, footings and substations;
- Fragmentation of habitats due to construction of the linear infrastructure needed for onshore wind farms, including access roads and transmission lines;
- Aquatic and terrestrial habitats can potentially be affected by various activities: widening of road sections or trimming/removal of roadside vegetation; and strengthening (or building) bridges and culverts;
- Indirect impacts on biodiversity due to the construction of new access roads in previously remote natural habitats. Increased accessibility provides more opportunities for illegal logging and poaching;
- Risk of bird, bat and insect[6] collisions and mortality with moving wind turbine blades during operation (Box 6.2);
- Permanent habitat loss due to disturbance and barrier effects on species. Operational wind turbines can disturb resident and transitory species (i.e., both terrestrial and birds/bats)—rotating turbines can cause avoidance or movement pattern changes, effectively creating “barriers” to habitats, resources, or the linkages between them. Important bird and bat migration pathways may be affected by improper siting of wind power facilities.

[5] World Bank (2015)

[6] Evidence is accumulating that insects are frequently killed by operating wind turbines, yet it is poorly understood if these fatalities cause population declines and changes in assemblage structures on various spatial scales (see: Insect fatalities at wind turbines as biodiversity sinks | Tethys (pnnl.gov) )

The creation of linear infrastructure including roads and transmission lines can often result in corridors of cleared vegetation or removed habitat. These “corridors” can cause habitat fragmentation by dividing up previously contiguous units of habitat.

Linear developments, including roads and transmission lines pose various direct threats to wildlife such as the risk of collisions and resultant mortality with vehicles and electrocutions, impeded access to resources (e.g., food), reduced genetic exchange, behavioural changes, and exposure to pollution. The impact of these corridors on arboreal mammals could be especially pronounced given their aversion to using open ground when the connectivity of the (tree) canopy is lost.

Bird and bat death associated with turbines is a significant problem where protected species are present and migratory and foraging routes are in proximity to onshore wind farms[7] [8]. There has been extensive research on the interaction between birds, bats, and wind turbines. In 2022, the US Synthesis of Environmental Effects Research prepared a briefing paper on Bat and Bird Interaction with Wind Energy Development[9].

The species that are killed by wind turbines are often long-lived, slow to reproduce, K-selected species[10], for which impacts on a few adults in the population can lead to significant population-level declines. This differs from those predominantly passerine species that are subject to collision with buildings or predation by cats, because there is much more redundancy in those populations, and they can withstand a certain level of annual mortality. This is particularly important for bats which provide significant ecosystem services, e.g.:

- Insect-eating bats have been shown to benefit? agricultural outputs by reducing pest insects[11]. Wind farm proposals in areas where the main agricultural pests are night-flying insects should take this into account.
- Insect-eating bats may reduce the number of medically important insect pests such as mosquitoes[12];
- Fruit-eating bats are important seed dispersers and pollinators and may be vital to forest regeneration[13].

[7] Thaxter *et al*. (2017)
[8] Is it possible to build wildlife-friendly windfarms? - BBC Future
[9] A table summarizing the more than 60 articles relevant to the subject is available at: https://tethys.pnnl.gov/summaries/bat-bird-interactions-offshore-wind-energy-development.
[10] K-selected species are those that reduce the number of offspring produced in order to increase their quality.
[11] e.g. Williams-Guillén *et al* (2009), Boyles *et al.* (2011), Noer *et al.* (2012).
[12] Reiskind and Wund (2009)
[13] Kunz *et al.* (2011), van Toor *et al.* (2019).

**Table 6.2: List of Key Environmental and Socioeconomic Issues for onshore wind power**

| ISSUE | CONCERN |
|---|---|
| **Environmental** | |
| Deforestation | • Land clearing and deforestation for wind farms sites and release of stored carbon |
| Habitats and biodiversity, and ecosystem services | • Changes to terrestrial habitats due to land clearing and linear developments<br>• Bird strikes or collisions (with spinning turbines) and barrier effect for local and migratory birds (including internationally listed endangered species) and bats. Often this loss is not fully recognized as predators may remove wildlife losses before they are detected.<br>• Potential loss of bat species—information about presence and distribution of bat species are often less established or absent (i.e., relative to bird species), requiring site-specific primary surveys to adequately assess impacts.<br>• Fragmentation of habitats by access roads and transmission lines<br>• Changed food webs<br>• Biodiversity impacts may also result from associated infrastructure (transmission lines, roads, and lighting), birds and bats may collide with overhead power lines leading to electrocution<br>• Due to the typical remote nature of onshore wind turbine generators, access road required for construction (e.g., wind turbine blade transportation) and operation and maintenance can potentially open new forest areas for exploitation in terms of illegal logging and poaching<br>• In many parts of the world bats and birds are vital to ecosystem functioning and their loss could destabilize entire ecosystems |
| Greenhouse gases | • Wind power can reduce GHG emissions where it displaces coal as a fuel source |
| Land-use changes | • Loss of agricultural and other productive land from siting of turbines and transmission lines |
| Protected areas | • Impact on protected areas, e.g., where wind farms are in, or nearby, protected areas or where access road and transmission lines pass through protected areas (through deforestation, disturbance to fauna, increased poaching, etc.) |
| Noise and vibrations | • Onshore construction noise from activities such as blasting, piling, construction of roads and turbine foundations, and the erection of the turbines themselves<br>• Operational noise impacts of onshore wind turbines may also have ongoing impacts<br>• Blade movement may disrupt behaviour and physiology of animals and cause physical damage (mortality to damage of hearing tissues and other organs)<br>• Anthropogenic noise can mask detection of biologically important signals used for communication, predator avoidance, and prey detection, and can influence behaviours<br>• Animals may move out of a noise area, potentially disrupting foraging, or breeding |
| Air quality | • Dust during construction<br>• Emissions from construction plant and vehicles—potentially on nearby residences or work sites (offices, etc.). Depends on volume of traffic |
| Waste | • Construction waste and decommissioning waste<br>• Wind turbine generator blades are made from unrecyclable composite materials and present a problem for disposal in most countries. However, new technology for recycling is emerging[14] |
| Water demand | • Water used during construction and operation—particularly an issue in arid environments |

[14] https://www.energy.gov/eere/wind/articles/carbon-rivers-makes-wind-turbine-blade-recycling-and-upcycling-reality-support

| ISSUE | CONCERN |
|---|---|
| Water quality | • Foundations, underground cables, roads, and infrastructure may result in increased erosion, soil compaction, increased runoff, and sedimentation of surface waters<br>• Discharge of pollutants in water (used for plant, equipment and vehicle washing) to ground and subsequent leaching to groundwater<br>• Release of pollutants (fuels, oils, chemicals, etc.) to groundwater during construction and decommissioning<br>• Accidental release of liquid wastes during storage, handling, and removal, with subsequent leaching to groundwater<br>• Accidental discharge of sanitary wastewater to ground and groundwater from the workers' domestic facilities |
| Metal and mineral extraction | • Overextraction of metals and minerals used for wind turbine manufacturing |
| Visual and aesthetic impacts | • The presence of many turbines, pylons, substations and transmission lines change landscape quality and disrupt the aesthetic value to the local communities<br>• Shadow flicker may become a problem with sensitive receptors nearby<br>• Wind turbines may reduce the appeal of an area for recreation and tourism |
| Land and ecosystem restoration | • Wind farms have a 20-30 year lifespan, after which restoration will be required, unless negotiations with landowners result in agreement to repower or upgrade the equipment and extend the wind farm's operational lifespan. |
| **Socioeconomic** | |
| Human rights | • Mineral mining companies (which supply wind turbine manufacturing companies) are known to violate rights of communities (e.g., rights to land, livelihood, ability to undertake traditional cultural practices)<br>• Mineral mining companies are known employ forced and child labour |
| Employment and labour conditions | • Employment opportunities during construction and operation phases of wind farms<br>• Job opportunities generated from new investment in mineral extraction for use in turbine manufacturing<br>• Worker safety (e.g., working at heights) |
| Health and safety | • Failure of rotor blades<br>• Failure and toppling of tower structures due to heavy forces of moving blades<br>• Heavy load transportation causes traffic management/safety problems<br>• Increased vehicular traffic during construction<br>• Burns or electrocution from electrical shocks or arc flashes/fires |
| Local economy and livelihoods | • Income from agricultural land will be lost<br>• Local communities can gain from benefit-sharing schemes<br>• Individual land owners may receive lease payments but these may be less than those received from other sectors (e.g. oil/gas)<br>• Concerns about liability and restoration costs of failed or terminated projects. |
| Shadow flicker | • Shadow flicker (which occurs when the sun passes behind a wind turbine casting a shadow) may become a problem with sensitive receptors nearby |
| Gender and vulnerability | • Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and indigenous communities) may be disadvantaged and at particular risk<br>• Employment opportunities within new projects<br>• Opportunities for vulnerable groups to acquire new skills and learn new technologies |
| Cultural heritage | • Risk of damaging or destroying cultural, historic and archaeological sites |
| Migration | • Tension between immigrants and workers<br>• Risk of gender-based violence due to influx of predominantly male construction workers |

| ISSUE | CONCERN |
| --- | --- |
| | • Pressure on preexisting health services and infrastructure |
| Telecommunications and aviation | • Electromagnetic interference to telecommunications systems<br>• Potential to impact aircraft safety with direct collision or alteration to flight paths.<br>• Some disruptions to aviation radar may be caused by turbines such as signal distortion |
| Public services and infrastructure | • Wind farm companies may fund Improvements to local infrastructure<br>• Pressure on local infrastructure due to heavy transportation of wind turbine equipment<br>• Increased pressure on public services, including health centers<br>• Increased local government's tax revenues generated from wind farm companies |

**Box 6.2: Impacts on migrating birds of large wind farm projects in Egypt near the Gulf of Suez**

An SEA was undertaken covering an area of 284 km² about 5 km inland from the shores of the Gulf of Suez located north-west of Ras Ghareb in Egypt. It assessed the likely environmental and social risks and impacts of future wind farm developments in the area.

Parts of the Gulf of Suez, especially the area near Gabel el Zayt, are well known as a bottleneck for migrating birds from Europe and western Asia and there were concerns that installing large wind farms in this region may lead to significant impacts on migrating birds caused by collisions with wind turbines or - to a lower degree - by barrier effects. In addition, large wind farms might even affect roosting and local (i.e., breeding) birds by direct habitat degradation or indirect disturbance (due to avoidance behaviour of birds).

As part of the SEA, extensive monitoring on birds was conducted in accordance with the EIA guidelines and monitoring protocols for wind energy development projects in Egypt. The monitoring aimed to collect baseline data on large soaring birds (mainly storks, pelicans, and raptors ("target species")), roosting and local birds. On that basis likely impacts caused by multiple wind-farm projects in the area were identified and assessed and appropriate mitigation measures to minimize impacts were defined.

The monitoring focused on bird migration during three different periods: April- May 2016 (spring migration and breeding period); September-November 2016 (autumn migration); and February-May 2017 (spring migration and breeding period)

Though migration of target species was low during some periods, a very high migratory activity was obtained on single days (probably - at least partly - correlated with low wind speeds). Relevant numbers of "Endangered" or "Vulnerable" species occurred in the study area, in particular Steppe Eagle with 4,740 individuals in spring 2017. More than 1 % of the flyway population of ten target species was observed in the whole study area and even at single observation sites. The monitoring confirmed that the area is of high importance for large soaring birds in spring.

The SEA recommended that, to reduce collision risk for large soaring birds at an individual wind farm level during spring migration, an effective shutdown, or curtailment, program should be established. Two alternate approaches were proposed:

- Fixed shutdown - during the critical migration period in spring (March 1st to May 18th) during daytime (i.e., 1.5 hour after sunrise to 1.5 hour before sunset);

- Shutdown on-demand - turbines are stopped in times of high collision risks, i.e., during periods of high migratory activity or when large flocks approach a wind farm. At two large wind farms, four criteria for triggering the shutdown of turbines were applied:

    1. Threatened species
    2. Flocks with 10 or more large soaring birds (target species)
    3. Imminent high risk of collision
    4. Sand storm of high migratory activity or when large flocks approach a wind farm

*Source: Lahmeyer and Ecoda Consultants (2018)*

Not all habitat and biodiversity outcomes are negative. Research after constructing wind turbines in the Gobi Desert concluded the development was a win-win strategy that both contributed to the growth of desert vegetation with the advent of a favourable microclimate[15].

Materials used to construct wind turbines comprise of steel, fiberglass, resin or plastic, iron, copper, and aluminium. The magnets used in modern turbines are made using neodymium and dysprosium.

[15] Kang *et al.* (2019)

The supply chain and source for these materials, and the potential adverse effects to habitat and biodiversity in the locations they are mined also need to be considered.

***Protected areas***

Onshore wind farms and their supporting infrastructure can have negative impacts on protected areas and areas of biodiversity importance —either directly by being located within a terrestrial protected area, or indirectly by impacting on the environment near a protected area or area of Biodiversity importance.

Protected areas of local, regional or international importance may include national and international protected areas (including marine protected areas); Important Bird Areas, Key Biodiversity Areas; Alliance for Zero Extinction sites; Ramsar sites (wetlands of international importance); known congregatory sites and unique or threatened ecosystems.

These sites may be on important migration routes, particularly for birds, or for wetlands or staging, foraging, or breeding areas. They may house bat hibernation areas and roosts, or they may contain important topographical features, including ridges, river valleys, shorelines, and riparian areas[16].

***Noise and vibration***

Noise can be an issue during both the construction and operation of a wind farm. It can affect nearby residents and communities as well as disturb wildlife. Localized vibration impacts associated with heavy machinery movement may occur during construction but are not evident once the turbine construction is completed and operation has commenced.

<u>During Construction</u>

During the construction of an onshore wind farm noise, and in some circumstances, noise and vibration is generated by:

- The building of access roads and hardstanding (hard surfaces);
- The erection of wind turbines which includes foundation preparation, tower installation, blade assembly and electrical infrastructure works;
- Increased traffic noise from delivery and construction vehicles.

Most wind farm projects are located in remote locations away from areas sensitive to noise and vibration. As a result, in most circumstances, construction noise and vibration are limited to few sensitive receivers.

*<u>During Operation</u>*

Noise generation during operation is primarily from the wind turbines themselves. It is caused by aerodynamic turbulence associated with the rotating blades (creating a swishing effect that is commonly audible near each wind turbine) and mechanical noises from within the nacelle. The nacelle houses the gearbox, generator, and drive train at the back of the turbine blades atop the turbine tower (

**Figure 6.3**).

Wind turbine noise is often assessed for the presence of any special audible characteristics that may cause subjective annoyance and therefore increased impact on adjacent noise sensitive areas. The

[16] World Bank (2015)

characteristics that are typically assessed include tonality, amplitude modulation, intermittency, low-frequency noise, and infrasound.

**Figure 6.3: Components of a wind turbine**

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Ancillary power infrastructure such as transformers and substations also cause some noise, but the impact is typically localized and close to the turbines, with no sensitive receivers in immediate proximity.

***Visual and aesthetic Impacts***

The World Bank Group EHS Guidelines[17] note that wind farm projects can have landscape and visual aesthetic impacts on local communities and change the visual context and setting of the natural landscape.

When the sun passes behind rotating wind turbine blades, it casts a shadow causing a flickering shadow effect. Shadow flicker may become a problem when potentially sensitive receptors (e.g., residential properties, workplaces, learning and/or health care spaces/facilities) are located nearby. The problem is likely to be of more significance at high latitudes where the angle of the sun causes longer shadows (i.e., has a large radius of influence) and the magnitude and extent is dependent on the duration, timing, and presence of sensitive receptors[18].

Local communities may view wind farms as impairing the aesthetic value of their surroundings. Some tourists find wind farms attractive, while others consider that they obstruct the natural landscape[19]. More than a decade ago, wind farms were being touted in the US as a means of boosting tourism and it was found that some tourists were supportive of wind farms being developed near recreation areas[20].

There are also documented cases of opposition to wind farms because they deter tourism. For instance, research in Germany showed that wind farms were perceived to negatively affect the landscape and views in tourist areas[21]. In some low-income areas, stakeholder concerns about aesthetics are less prevalent or receive less prominence in project decision-making. In certain situations, wind farms can create conflicts between community groups having different perspectives. This can only be expected to increase as the intensity of wind power development increases on the landscape as a result of the energy transition.

***Air quality***

[17] World Bank (2015)
[18] Parsons Brinckerhoff (2011a and 2011b)
[19] NRC (2007)
[20] Brown (2014)
[21] Broekel and Alfken (2015)

Wind farms have negligible impacts on air quality when operational. The main issues are usually dust and vehicular emissions during the construction of access roads and excavations for the turbine towers.

### *Water quality*

Similarly, onshore wind farms have minimal impacts on water quality. During construction, there can be localized increased turbidity in water courses due to soil erosion along access routes and at turbine construction sites. This usually arises if measures to manage soil erosion and drainage are lacking or inadequate.

There can be small-scale spills of hazardous substances such as oils or vehicle fuel during construction. These have a temporary impact on water quality.

Depending on the technology, wind turbines may require water for cooling the generator, transformer, and inverter, and occasional for blade washing to maintain efficiency. This will require abstraction for a local water resource, particularly when local rain patterns are insufficient. Supplies of water available to local communities may be reduced, particularly during dry seasons.

Subject to any additives used, each of these activities pose limited risks to catchment water quality given that only low volumes of water are used.

### *Waste*

Overall, waste production during the construction and operation of an onshore wind farm is not significant. The tower and nacelle are usually made from recyclable steel and copper. Materials used to construct wind turbines include steel, fiberglass, resin or plastic, iron, copper, and aluminium. The magnets used in modern turbines are made using rare earths (primarily neodymium and dysprosium). Typically, 85% of a decommissioned wind farm can be recycled.

From a life cycle perspective, the blades (service life of 20–30 years) currently account for most of the nonrecyclable waste (plastic polymer and composite materials) from wind turbines when they are decommissioned at the end-of-life, or when wind farms are being upgraded in a process known as repowering. The latter involves keeping the same site and often maintaining or reusing the primary infrastructure but upgrading with larger capacity turbines. During repowering, the blades might be replaced with more modern and typically larger blades.
Wind turbine blades are significant in size and disposing them at their end-of-life of blades involves a complex value chain with several steps and stakeholders. It has been forecasted that, by 2050, the end-of-life waste stream of wind turbine generator blades (from onshore and offshore wind farms) could, cumulatively, be as much as 43 million tonnes worldwide with China possessing 40% of the waste, Europe 25%, the United States 16%, and the rest of the world 19%[22].

Decommissioning, reusing, and repurposing blades is an option (Figure 6.4), but this can be a challenge for some countries[23]. In late 2021, Siemens Gamesa Renewable Energy launched the world's first fully recyclable wind turbine blade at its manufacturing plant in Denmark.

**Figure 6.4: Section of a wind turbine blade repurposed as a bike shelter in Denmark**

[22] Liu and Barlow (2017)
[23] Beauson *et al.* (2022)

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In 2023, Vestas, a wind turbine manufacturer announced that it has discovered a new chemical process which removes the need to change the design or composition of the material used for wind turbine blades to make them recyclable[24]. It breaks down epoxy-based blades into raw material that can be reused to make new wind turbine blades or to be used for other purposes. Vestas plans to scale up the newly discovered chemical disassembly process into a commercial solution in partnership with other companies. If successful, this will eliminate the need for blade redesign, or landfill disposal of epoxy-based blades when they are decommissioned.

***Land and ecosystem restoration***

As discussed above, there are significant risks associated with wind power development with regard to potential environmental harm and degradation, e.g., unnecessary or excessive deforestation when constructing new access roads and transmission lines, destruction of habitats and loss of biodiversity and ecosystem services as well as soil erosion and pollution. This will particularly arise where mitigation measures proposed by a SEA (and subsequent project-level EIAs) are inadequate, ineffective or not undertaken. The significance and seriousness of such degradation can be compounded where the impacts are cumulative and extensive. Such cumulative impacts will be highly likely to occur where there are multiple wind farm developments across landscapes.

Such impacts will usually lead to demand for and need for land and ecosystem restoration (see Box 3.9). This need will also arise at sites of projects that have come to the end of their useful operational life – usually after 20-30 years[25]. After this time, the project owner will either decommission the site, restoring the area to its previous land use, or negotiate with landowners to repower or upgrade the equipment and extend the wind farm's operational lifespan.

Scottish Natural Heritage has developed guidance for the preparation of decommissioning and restoration plans (DRP) for on-shore wind farms[26]. The guidance is focussed on the process of producing a DRP and does not provide detailed advice on methods as each site will have different environmental conditions, as well as different turbine, track and other infrastructure specifications. It is focussed on natural heritage issues and does not provide guidance on matters such as health and safety or the reuse of materials.

Given that exisiting most wind power projects were installed to supplant power generation from conventional fossil fuel sources and that they were likely to have been installed at the optimal location to maximize wind flow, it is likely that most wind projects will continue in the future with upgrades to equipment rather than decommissioning and restoration.

### *6.4.3 Key socio-economic issues and impacts for onshore wind power*

24 Newly Discovered Chemical Process Renders All Existing Wind Turbine Blades Recyclable - World-Energy

25 The average lifespan of wind turbine generators is about 20 years.

26 Scottish Natural Heritage (2016)

***Employment and labour conditions***

Wind farm development projects can create job opportunities for skilled and unskilled workers in the host communities and from other places. In 2020, 1.25 million jobs were recorded in the wind industry. It is estimated that, globally, up to 7 million jobs will be generated by wind by early 2030[27] (Figure 6.5).

**Figure 6.5: Global wind power jobs are in the millions and projected to increase**

Figure redacted pending securing copyright permission to use. If you have an image showing this spatial distribution that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

In Asia, the employment numbers are particularly high: 550,000 in the PRC and 40,000 in India. A British wind industry report*28* suggests that approximately 15%–20% of the project cost of a wind energy development is for labour, which requires skills*29* typically available from local contractors. Wind farm projects tend to create a relatively small number of employment opportunities for local workers (compared to other renewable energy technologies) during the construction phase, which is often not long (depending on size, between six and 20 months). More jobs can be created depending on the transmission line, substation, and access road requirements. The rest of the labour cost is for more complex and specialist tasks*30*.

The operation and maintenance of wind farms usually requires a very small number of staff and relies on specialist skills. Some companies use drones for wind farm inspections, reducing employment opportunities*31*. Depending on their location, some wind projects will have a large regiment of security staff (normally local) to patrol large areas.

Statistics provided by IRENA*32* do not include employment opportunities in the manufacturing and supply chains of wind turbine generators and blades. As demand for wind turbines increases, there will be more investment in extraction of the metals and minerals required to manufacture wind turbines, and thus more job opportunities created along the turbine supply chain line.

All projects have potential to involve unfair treatment and/or remuneration, discrimination in labour decisions, inappropriate recruitment, and poor working conditions*33*. There can also be unsatisfactory employment arrangements, especially for projects that involve complex supply chains of materials, and various contracting tiers*34*. However, many wind projects are well-managed and mitigate such risks. The main infringement of labour rights during construction are related to requirements for excessive overtime and successive days of work without sufficient rest (see discussion of employment and labour conditions in Chapter 6). In addition, some smaller wind projects may use casual workers

[27] IRENA (2021a)
[28] CSE (2009)
[29] These include supplying and pouring concrete, laying cables and basic civil engineering tasks (such as tracks and hard-standing, foundations, trench digging for cables, basic construction for substation housing)
[30] Engineering consultancy, specialist craning, cables and sub-station equipment, and, most significantly, the manufacture and assembly of the wind turbines themselves
[31] Renewable Energy World (2017)
[32] IRENA (2021a)
[33] Rutherford, N. (2021)
[34] Actionaid (2018)

who do not have sufficient training on the environmental and social management system to meet GIIP. The sub-section on human rights discusses issues concerning the infringement of workers' rights in the supply chains of wind turbines.

***Local economy and livelihoods***

As with many development activities in rural areas, onshore wind projects often pose a range of risks associated with acquiring land for wind turbine generators, access roads, substations, and transmission lines. Additional land may also be required for associated facilities such as offices and storage sheds, although these are generally not large. During construction, there can be temporary land use needs for workers' accommodation, stockpiles, and laydown areas.

Land acquisition and restrictions on land use can cause both physical and economic displacement. There can be building restrictions (like transmission lines) for land closest to the wind turbine generators. Wind farms (whether linear or disparate) generally require a low amount of land-take. They can easily coexist with a range of land uses, e.g., agriculture and pastoralism[35]. Wind turbine generators typically have small footprints, so physical displacement (relocation) can often be avoided or minimized. In countries in Southeast Asia, wind farms do not appear so far to have caused controversy over land acquisition, nor to have had impacts on livelihoods. In other countries where wind farms have been developed on grazing land (e.g., Uruguay, Mexico, Kenya, and Mongolia), there has been minimal economic displacement or adverse impacts on affected people's livelihoods.

Wind farm companies frequently use leasing arrangements, entering negotiated voluntary land agreements. When a landowner is not interested, the company then modifies the micro-siting arrangements to work with others amenable to an agreement. Leasing agreements (usually for 20 to 50 years) allow companies to pay for smaller footprints (usually in acres) of wider land packages. Payments can combine installation fees for each wind turbine, including access rights plus annual payments.

Challenges can arise when a landowner makes an agreement with the wind company, but renters or neighbours are residing close enough to be affected by the noise or shadow flicker effects.
It is important that companies obtain valid land valuations. Wind projects in Central and South America have faced protests over land under communal use, including by indigenous communities, when it has emerged that the projects have negotiated leases at rates that are below actual land value. In Mexico, where landowners and users cede their property permanently or temporarily for energy projects[36], some community members have protested about previously agreed land access by erecting barriers to acquired plots during construction, causing project companies to renegotiate the land rates. The proposed scale of massive wind developments can also be problematic.

Wind farm construction generally requires a small workforce—using local workers plus some non-local workers with specialist skills for short periods of time. In most instances, the non-local workers will rent accommodation. In locations where availability of such housing is limited, rental prices can increase temporarily and a short boost to a localized economy may occur.

Benefit-sharing (including the payment of royalties) tends to be more typical for hydropower projects rather than wind. But the Windplan Groen project in Flevoland province in the Netherlands is an example where local communities are allowed to invest in the project[37].

The conditions for the construction of the wind turbines of Windplan Groen state that local residents may participate in 2.5% of the total investment. The initiators do not borrow that amount from the banks but from residents who receive an interest payment for it. With a total estimated investment of 500 million euros, the neighbourhood can therefore participate for approximately 12.5 million euros.

[35] The Dam Nai Wind Project - Vietnam (operated by the Blue Circle energy company) provides an example of combining rice cultivation and wind energy generation.
[36] Payan and Correa-Cabrera (2014)
[37] www.windplangroen.nl

***Health and safety***

The IFC's environmental health and safety guidelines[38] recognize that wind turbine projects can pose health and safety risks for both the local workforce and the local community.

***Local workforce***

*Occupational health and safety hazards during the construction, operation, and decommissioning of* onshore and offshore wind energy facilities are generally like those of most large industrial facilities and infrastructure projects. During construction and operation, these may include physical hazards such as working at heights and falling objects, working in confined spaces, working with rotating machinery, remote locations, electrocution or burn risk and lifting operations.

***Local community***

The main community health and safety impacts are blade and ice throw, aviation, electromagnetic interference and radiation, public access and abnormal (large or oversized) load transportation[39].

Blade throw is likely to occur very infrequently, often during storms or due to malfunction. Ice throw can occur in colder climates when moisture freezes to the blade surface but dislodges during operation.

An emerging safety risk is the failure and collapse of wind turbine systems. Reasons for this are being investigated and may relate to production issues or the increasing size of blades and towers.

If wind turbines need to be located near airports, military low-flying areas or known flight paths, a wind energy facility (including anemometer mast) may impact aircraft safety directly through potential collision, or indirectly by requiring alteration of flight paths. Correct site selection minimizes these risks.

Wind turbines can also cause electromagnetic interference with telecommunication systems (e.g., microwave, television, and radio). This interference could be caused by path obstruction, shadowing, reflection, scattering or re-radiation. Further information on telecommunications and aviation is provided in the ensuing paragraphs on aviation and telecommunications in this chapter.

Safety issues may arise with public access to wind turbines (e.g., unauthorized climbing of the turbine) or to the wind energy facility substation. Adequate fencing and signage minimize this risk.

One of the main challenges with respect to wind energy facilities lies with the transportation of oversized or heavy wind turbine components (blades, turbine tower sections, nacelle, and transformers) and cranes to the site. Transportation of these oversized loads pose safety risks to the community if not planned, managed, and escorted properly.

***Gender and vulnerability***

Areas with the highest wind power potential are remote deserts, plains, and mountain tops - often places with lower-income rural populations, marginalized groups, and indigenous people This can lead to displacement (see previous subsection) and can impact women and vulnerable groups[40].

There is considerably less physical and economic displacement associated with onshore wind projects than with other types of renewable power generation such as hydropower facilities or solar farms. There are plentiful opportunities for employment during the construction phase of onshore wind projects. It is calculated that there are 1.2 million jobs in the onshore wind power sub-sector globally, 56% of which are in the Asia region. However, only 21% of all global jobs in the sub-sector are held by

[38] IFC (2015)
[39] IFC (2015)
[40] Differential impacts of displacement and access to any resulting benefits are explored in greater detail in the Hydropower: Gender and Vulnerability subsection in this report.

women. Existing negative perceptions of gender roles and cultural social norms are seen as major barriers to gender equality in the sub-sector[41].

Box 6.3 provides an example of a programme that aims to promote more gender-inclusive planning processes, sub-sector employment, training, and skills development within the wind energy sub-sector.

**Box 6.3: Women in Wind Global Leadership Programme**

The Women in Wind Global Leadership Programme was launched in 2019 by the Global Wind Energy Council (GWEC), in partnership with the Global Women's Network for the Energy Transition (GWNET). It is designed to accelerate women's careers, support their pathway to leadership positions, and foster a global network of mentorship, knowledge-sharing, and empowerment.

*Source: Global Wind Energy Council (https://gwec.net/women-in-wind/about-the-program/)*

***Indigenous communities***

In areas where indigenous people are located, the development of wind farm projects needs to consider the potential impacts on communal land and traditional practices. Most wind farms are not fenced, and, because of their small footprints, there is usually minimal loss of access to natural and cultural resources such as sacred forests, burial grounds, and animistic sites. However, there are some high-profile cases where groups have protested about not being properly consulted and about their free prior and informed consent to wind farm projects not being sought. In Norway, the indigenous Sami people have been struggling to preserve their culture and identity as well as their main source of livelihood, reindeer husbandry, and claimed that a wind farm disturbed their reindeer husbandry[42]. In La Guajira, Colombia, indigenous Wayúu people protested wind farm companies which "grabbed" their sacred land, affecting their cultural identity and practices[43].

Members of local indigenous communities can benefit from some employment opportunities in wind farm projects, either during construction or operations. Skill development and industry participation programs for the local and indigenous communities may be provided by wind energy companies, mainly during construction since, during operation, wind farms generally have very low permanent workforces.

***Cultural heritage***

Wind farms and associated infrastructure such as transmission lines and access roads can cause damage to cultural, religious, historical, and archaeological sites (both tangible and intangible heritage) —mainly during construction. However, there are substantial opportunities to design and microsite the turbines to avoid adverse impacts on cultural heritage. The process of seeking free, prior, and informed consent and Broad Community Support (for ADB SPS) can help to identify such sites and avoid adverse impacts on them.

***Telecommunications and aviation***

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[41] IRENA (2020)
[42] aNews (2021)
[43] National Wind Watch (2021)

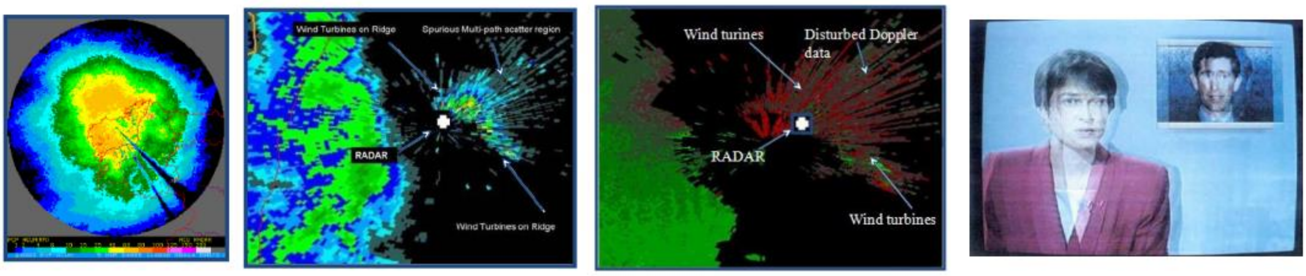
Wind farms can interfere with electromagnetics, radar signals and telecommunications systems, including local mobile phone coverage and quality. The operation of wind farms may also disrupt aviation radar through signal distortion – with associated safety risks. The degree and nature of the interference will depend on[44]:

- The location of the wind turbine between receiver and transmitter;
- Characteristics of the rotor blades;
- Signal frequency:
- Air traffic control radar;
- Air navigation systems, and
- The radio wave propagation in the local atmosphere.

Wind turbines are much larger signal reflectors than those actually targeted by radar systems. Their presence may hide weaker response signals from smaller targets. The rotating blades generate a Doppler shift which is also detected by radar systems. Radar systems are not designed to identify and filter out signals from wind turbines - so important information from the surroundings of a wind farm may be lost, as demonstrated in
Figure **6.6**. This can be due to the proximity of wind farms and telecommunication antennae (**Error! Reference source not found.**).

**Figure 6.6: Examples of the effects of wind turbines on weather radar, air traffic control, radio, and television.**

*Source: Angulo et al. (2014)*




[44] Wind Energy. Electromagnetic interferences (wind-energy-the-facts.org).

**Figure 6.7: Wind farm and Telecommunication Antenna Installed Near Each Other**

Source*:* [https://www.ewea.org/annual2014/conference/programme/info2.php?id2=1091&id=52%20&ordre=1](https://www.ewea.org/annual2014/conference/programme/info2.php?id2=1091&id=52%20&ordre=1))

Wind turbine blade tips can be up to 200 meters tall and, in the future, may exceed this height as the technology evolves. So, if located near airports, military low-flying areas or known flight paths, a wind energy facility could create a risk of collision or require the alteration of flight paths[45]. Such impacts can be avoided and addressed through design, siting, and mitigation measures such as marking systems and signal boosting equipment.

***Public services and infrastructure***

Communities near wind farms can be affected by the transfer of oversized and abnormal loads carrying large and heavy wind turbine parts (blades, turbine tower sections, nacelles, and transformers) (

**Box 6.4: Community development activities funded by the Lake Turkana**

For the Lake Turkana Wind Power project (one of the largest wind farms in Africa), the Winds of Change (WOC) Foundation was established to disburse €10 million over the 20-year operational life. The WOC programme undertakes sustainable community development activities in the project catchment area focusing on education, health, and water.

*Source: WINDS OF CHANGE – Lake Turkana Wind Power (ltwp.co.ke)*

[45] FINAL_Aug+2015_Wind+Energy_EHS+Guideline.pdf (ifc.org)

**Figure 6.8:** ). While this will be once and one way during construction, such transportation can damage existing roads. Permits from transportation authorities and often police or other escorts can be needed. In some instances, road upgrades may also be needed.

Local infrastructure and facilities can be improved by the onshore wind companies' corporate responsibility investment programs. Wind farms developers sometimes establish community investment programs commensurate with their size (**Error! Reference source not found.**6.5. These corporate responsibility activities will generally be small contributions to existing activities run by other organizations.

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*Source: WINDS OF CHANGE – Lake Turkana Wind Power (ltwp.co.ke)*

**Figure 6.8: Land-based wind turbine blade transportation**

Figure redacted pending securing copyright permission to use. If you have an image showing this spatial distribution that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

***Human rights***

There are significant human rights risks in the supply chains through which raw materials needed for wind farm equipment are sourced. The manufacture of onshore wind turbine components requires rare earth and other minerals. The process of extracting mineral resources and supplying such resources for wind turbine manufacturing can infringe the rights of both indigenous and non-indigenous communities (and there are examples where it has), including but not limited to rights to land, land ownership, natural resources, customary land uses, and adequate living standards.

## 6.5 OFFSHORE WIND POWER GENERATION

### *6.5.1 Offshore installation types*

Offshore wind has been in commercial operation in parts of Europe since the early 1990s. In 2021, globally, there was 57 GW of installed offshore wind power capacity.

Offshore wind farms can be located tens of kilometres from the coastline. Construction generally involves foundation structures (e.g., piles or caissons) being installed into the seabed on which fixed wind turbines are mounted. Floating wind farms are also an option in some locations and can offer potential where there were previous technological constraints to deploying fixed wind power structures.

Large, specialized working vessels are used to undertake the foundation works and for the erection of wind turbines as well as to transport project components to offshore sites. Offshore turbines can also be built taller than those onshore, as there is opportunity to capture energy from higher and more constant winds. An intriguing opportunity is to look at converting abandoned offshore oil platforms to house offshore electrolysers for the purpose of generating green hydrogen from electricity produced from offshore wind farms.

**Figure** 6.9 shows the locations of mines for these materials (including from Southeast Asia). Some of the locations, including in low and middle-income countries, include places where there are conflicts or where human rights are not well-regulated or enforced.

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[46] GWEC (2022)

[47] https://www.rechargenews.com/energy-transition/worlds-first-offshore-green-hydrogen-project-on-an-oil-platform-gets-go-ahead/2-1-1043998

**Figure 6.9: Producers of minerals and metals used in wind turbines**

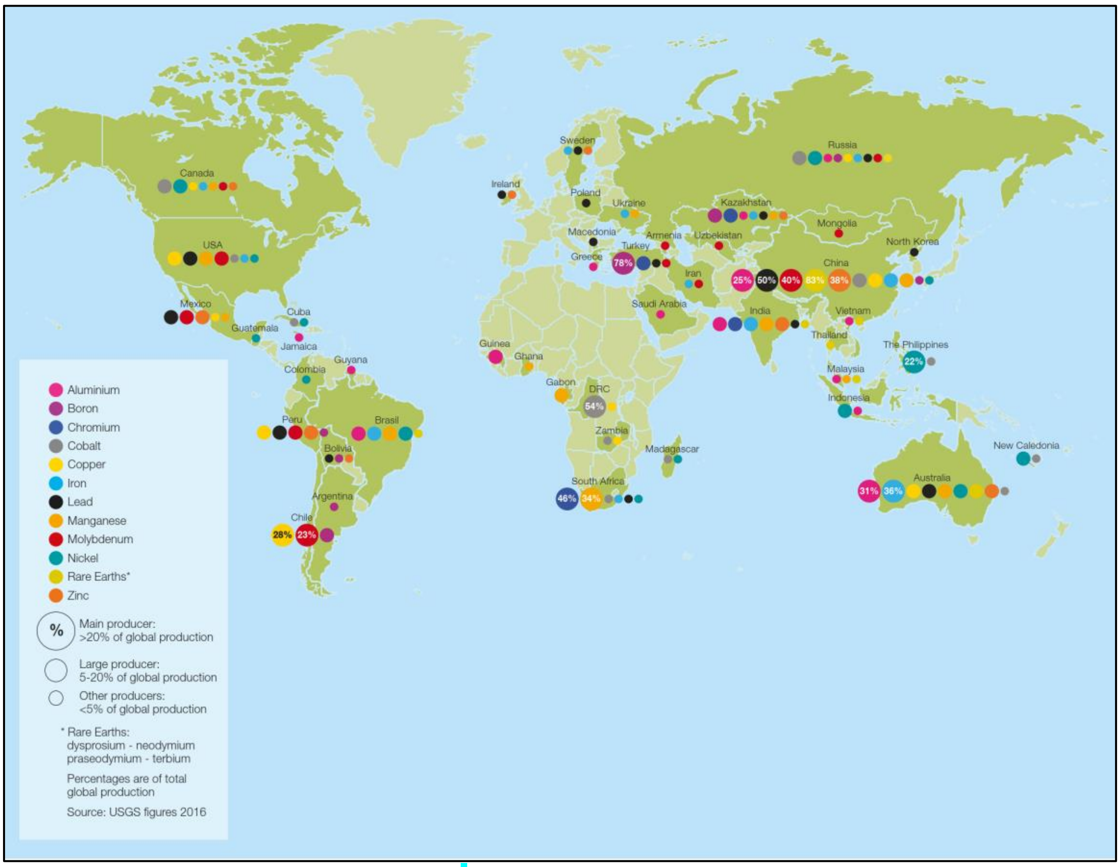

*Photo credit: Action Aid (2018) and SOMO [*

Each offshore wind turbine is connected via submarine inter-array cables to export the electricity generated back to land (i.e., via a submarine export cable) where it is fed into the electricity grid.

Depending on the distance offshore of the wind farm, an offshore substation might also be required in addition to the onshore transmission components such as substations and terrestrial transmission lines (**Error! Reference source not found.**).

Offshore wind farms have a high energy output per square meter ($m^2$) and can be built up quickly at gigawatt-scale, so they are a valuable option to provide electricity to densely populated coastal areas in a cost-effective manner. Developments in turbine technologies as well as in foundations, installation, access, operation, and system integration have made possible the move into deeper waters and farther from shore, and thus to exploit sites with greater energy potential. Over the last 5–10 years, offshore wind has reached maturity, making it the most advanced technology among offshore renewables[48].

[48] IRENA (2021b)

**Figure 6.10: Offshore wind farm key components**

Figure redacted pending securing copyright permission to use. If you have an image showing this spatial distribution that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

The largest windfarm in the world is being developed at Dogger Bank off the coast of England (Box 6.5).

**Box 6.5: Dogger Bank windfarm, England, UK**

Dogger Bank Wind Farm offshore wind farm is being developed in three phases – Dogger Bank A, B and C – located between 130km and 190km from the North East coast of England at their nearest points. Collectively they will become the world's largest offshore wind farm. Each phase will have an installed generation capacity of 1.2GW. Combined, they will have an installed capacity of 3.6GW and will be capable of powering up to 6 million homes annually.

The investment in the Dogger Bank C wind farm is estimated to be £3bn ($3.99bn). Figure 6.11 shows a Voltaire jack-up installation vessel with a lifting capacity of more than 3,000t to deliver the turbines and install on foundations. The project will occupy an area of approximately 560km$^2$ and is expected to generate approximately 6TWh of clean and renewable electricity to be fed into the UK's national power grid. First power is expected in the third quarter (Q3) of 2025, while the wind farm will become fully operational in Q1 2026. Dogger Bank C will have an estimated operational life of approximately 35 years[49].

**Figure 6.11: Dogger Bank C windfarm**

Figure redacted pending securing copyright permission to use. If you have an image showing this spatial distribution that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

### 6.5.2 Key environmental Issues and impacts for offshore wind power

Table 6.3 summarises the key environmental and socio-concerns concerns likely to be associated with offshore wind power development. While some potential environmental impacts (direct and indirect) of offshore wind farms during construction and operation are the same as for onshore projects, others are unique to the marine environment.

[49] Dogger Bank C Offshore Wind Farm, North Sea, UK (power-technology.com)

**Table 6.3: List of Key Environmental and socioeconomic issues for offshore wind power**

| ISSUE | CONCERN |
|---|---|
| **Environmental** | |
| Protected areas | • Impact (incursion) on marine protected areas (MPAs) |
| Habitats and biodiversity | • Changes to benthic and pelagic habitats, e.g., as result of changes in water quality due to sedimentation from construction activities<br>• Impacts on flora and fauna, e.g., bird strikes on spinning turbines for migrating and local birds (including internationally listed species) (offshore wind speeds tend to be faster and steadier than on land)<br>• Changed food webs<br>• Birds displaced from offshore foraging or roost sites<br>• Offshore structures may disturb existing habitats and attract new habitat-forming species, such as shellfish, corals, and underwater vegetation.<br>• Biodiversity impacts may also result from associated infrastructure (including underwater cables) and boat-based maintenance traffic (e.g., collisions with marine mammals).<br>• Marine mammals and other marine fauna may be killed by construction or supply vessels<br>• Direct loss of habitat resulting from clearing for onshore component and fragmentation of habitat from access roads and transmission lines |
| Noise and vibrations | • Noise and vibration from construction (on seabed) can disrupt biodiversity. Unless adequately mitigated and monitored, underwater noise generated during offshore piling could cause temporary or permanent adverse impacts to the hearing and behaviours of cetaceans (whales, dolphins, and porpoises) and pinnipeds (fin- or flipper-footed mammals)<br>• Operational noise from offshore wind turbines can disrupt behaviours, physiology of animals and fish and cause physical damage (mortality to damage of hearing tissues and other organs)<br>• Anthropogenic noise can mask detection of biologically important signals used for communication, predator avoidance, and prey detection, and can influence behaviours<br>• Aquatic animals may move out of a noise area, potentially disrupting foraging, or breeding<br>• Sound (pressure) can travel a long distance in the sea and ocean<br>• Noise from construction traffic and use of machinery during construction of onshore component |
| Air quality | • Onshore dust following soil disturbance and from vehicle traffic to coastal access point site and for onshore component |
| Water quality | • Installation of foundations and sub-surface cables could disturb the marine floor, increase suspended sediments, and decrease water quality, which could affect marine species and commercial or recreational fisheries.<br>• Dredging (e.g., possibly to extensive amount) could be required depending on the offshore wind turbine generator area’s bathymetry, foundation type, and working vessel depth requirements. The disturbance and suspension of seabed sediment could have adverse impacts to water quality<br>• Releasing pollutants (fuels, oils, chemicals, etc.) during construction, operation or decommissioning |

| ISSUE | CONCERN |
| --- | --- |
| | • From increased vessel traffic (to generation sites)<br>• Release of contaminants from seabed sediments |
| Greenhouse gases | • Wind power can reduce GHG emissions where it displaces coal as a fuel source |
| Waste | • Construction and operation waste as well as waste metals and hazardous materials during decommissioning<br>• Wind turbine generator blades are made from unrecyclable composite materials and present a problem for disposal in most countries. However, new technology for recycling is emerging |
| Seabed erosion | • Installation of offshore structures may result in localized seabed erosion due to changes in water movements |
| Mineral extraction | • Overextraction of metals and minerals used for wind turbine manufacturing |
| Visual and aesthetic impacts | • Turbines, pylons, and transmission lines change the landscape and disrupt the aesthetic value to the local communities<br>• May detract appeal of area for recreation/tourism |
| Marine and ecosystem restoration | • Offshore wind farms have a 20-30 year lifespan, after which restoration will be required, unless agreement is reached to repower or upgrade the equipment and extend the wind farm's operational lifespan. |
| **Socioeconomic** | |
| Human rights | • Mineral mining companies (which supply wind turbine manufacturing companies) are known to violate the rights of communities (e.g., rights to land, livelihood, ability to undertake traditional cultural practices)<br>• Mineral mining companies are known to employ forced and child labour |
| Employment and labour conditions | • Employment opportunities for construction and operational phases<br>• Job opportunities generated by new investment in mineral extraction |
| Health and safety | • Hazards to beach users during transportation and construction of the wind turbines or from landfall of electrical transmission cables<br>• Road closures or disruptions when transporting wind turbine components to site<br>• Noise of the wind turbine and blade may disturb communities<br>• Worker safety (e.g., working at heights, electrocution and fire risk) |
| Local economy and livelihoods | • Loss of income from marine fishing<br>• Temporary and long-term loss of access to fishing areas and interference with offshore fishery rights (commonly held by communities or fishery associations)<br>• Local communities can gain through benefit-sharing schemes |
| Gender and vulnerability | • Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and indigenous communities) may be disadvantaged and at particular risk<br>• Employment opportunities on new projects<br>• Opportunities for vulnerable groups to acquire new skills and learn new technologies |
| Recreation and tourism | • Interrupted and restricted access to public beaches and swimming areas due to the transportation of wind turbine components and construction of undersea cables |

| ISSUE | CONCERN |
|---|---|
| Marine navigation | • Interference with vessel traffic and safety, particularly when located near ports, harbors, or known shipping lanes<br>• Interference with radar used for shipping navigation |
| Telecommunications and aviation | • Electromagnetic interference to telecommunications systems<br>• Potential to affect aircraft safety with direct collision or alteration to flight paths<br>• Some disruptions to aviation radar may be caused by turbines (e.g., signal distortion) |
| Public services and infrastructure | • Wind farm companies may fund improved local infrastructure<br>• Onshore bases will be required to support offshore wind development which could lead to loss of habitat and construction and operational impacts<br>• Pressure on local infrastructure due to heavy transportation of wind turbine equipment<br>• Increased pressure on public services, including health centers<br>• Increased local government tax revenues generated from wind farms |
| Migration | • Tension between immigrants and workers<br>• Gender-based violence due to an influx of predominantly male construction workers<br>• Pressure on preexisting health services and infrastructure<br>• Onshore worker camps and accommodation cause social disruption |

***Habitats and biodiversity***

Some potential risks to habitat and biodiversity have been identified, including those documented by the IFC[50]. These include:

- Underwater noise impacts during construction (i.e., during piling, dredging, vessel movements) and operations. This can affect the hearing, echolocation and behaviour of fish, birds, cetaceans (whales, porpoises, dolphins) and pinnipeds (e.g., seals and walruses).

- Seabed (benthic) disturbance and new structures may also impact existing habitats and attract new habitat-forming species, such as shellfish, corals, and underwater vegetation[51] to colonize the disturbed areas.

- Water quality impacts due to sediment transport of cable laying and dredging activities as well as foundation works. This has potential to increase turbidity and that affects coral or seagrass ecosystems by reducing available light.

- Potential construction and operation impacts of hydrogen pipelines from offshore electrolyser production platforms to shore may impact marine biodiversity on the sea floor.

- Working vessels colliding with cetaceans and pinnipeds during construction. This is usually addressed through raising the awareness of vessel crews about the risks and implementing a well thought out marine traffic management plan (e.g., with speed limits, using routes that avoid key habitat areas).

- Permanent habitat loss due to disturbance and barrier effects on bird species when they adjust their behaviour to avoid offshore wind farms. In turn, this may limit or alter the way in which they utilize habitats, disrupt migratory paths or their movement between roosting and feeding sites.

- Noise. Mitigation measures to minimize the effects of noise during construction are well documented.[52]

- Potential behavioural and distributional changes to wildlife resulting from construction.

Other risks include:

- Where offshore wind farms have lights, these can attract birds at night;
- Where offshore wind farms are located near seabird colonies or between their colonies and foraging grounds. Collisions are potentially more likely under adverse weather conditions at sea with poor visibility[53] [54]

Bird collisions with turbine blades (migratory and pelagic (open sea) birds and bats is one of the most common impacts of offshore wind farms, particularly as they typically have a project life of 20–30 years. As a result, even a small increase in mortality during each migratory season can result in a greater impact over time. On average, offshore wind farms have a higher risk of bird collisions than those onshore due to several factors (listed below), except where the latter are located on migratory flyways and at sites with large, less manoeuvrable species, such as those that habitually soar in thermals[55]:

[50] IFC (2015)
[51] Köller *et al*.,(2006)
[52] e.g., Scottish Natural Heritage (2019) ; German Federal Agency for Nature Conservation (2013)
[53] Hüppop *et al*. (2006)
[54] Note: it is difficult to detect collisions at sea and difficult to monitor potential collisions, especially in stormy weather (Bennun *et al.* 2021; Pellow 2017, 2019)

[55] Exo *et al*. (2003)

- Offshore wind turbines are considerably taller with longer rotor blades resulting in higher tip-speeds and turbulence;
- The hearing of birds can be hampered by background noise from waves and winds in an offshore environment;
- Seabirds and waterfowl (and many terrestrial bird species) tend to fly low above the water surface (mostly <100m), especially during foraging and short sea crossings, coinciding with the blade sweep area of offshore turbines.

There are similar risks for bats during migration and during offshore foraging of insects at sea, although these are often limited to specific regions and collisions are generally less prevalent than for migratory birds.

Offshore wind farms may be located close to coastal habitats that host congregatory and migratory bird or bat species. For example, river estuaries, wetlands or islands. They can also be located near or within important regional or global flyways—flight paths used by large numbers of birds on a regular seasonal basis during their migration between their breeding grounds and overwintering quarters.

Wind farms located offshore require less land-take than onshore projects and therefore have less land-use change consequences and associated environmental impacts.

A beneficial aspect of an offshore wind farm is that its structures can provide substrates for the growth of new artificial reefs and habitat for marine life once colonized and established.

***Protected areas***

Offshore wind farms and their associated infrastructure can have negative impacts on protected areas at sea, either directly by being located within a protected area or indirectly by having an impact on the environment near a protected area.

The material impacts on protected areas are generally less than those caused by onshore wind turbines. The onshore components associated with an offshore wind farm typically include a cable landing point (on the coastal shore), terrestrial cables and, if required, an onshore substation. If these onshore components are accessible by existing roads or cannot connect to existing transmission lines, new access roads and transmission lines may need to be constructed. The onshore footprint of offshore turbines is typically much smaller than that of most other power generation technologies. But there is still a potential risk (albeit of less likelihood/magnitude) of negative impacts on terrestrial protected areas if any of these components are within or close to such areas.

The density of offshore wind turbines, and their potential effects on protected areas can vary. Assumptions made in available literature about or state-of-art and prospective capacity densities for European wind farms are in the range 5.0 – 5.4 MW/km [56] . Hence, even a modestly sized 100 MW offshore wind farm could require 20km$^2$ of offshore area. Such a significant area could potentially encroach on marine protected areas if offshore wind farms are developed at scale around the globe. The likelihood and significance of such encroachment could be greater where fixed bottom offshore wind farms (requiring shallow water depth) are developed near coastlines or islands where there are protected marine areas.

***Noise***

During construction, noise can arise due to:

- Foundation works, particularly if piling methods (monopiles or jacket foundations) are used;

[56] Interreg. 2018. BalticLINes_CapacityDensityStudy_June2018-1.pdf (vasab.org).

- Dredging and backfilling activities for cable laying or preparing foundation works, and
- Offshore project activities such as vessel movements and equipment operations.

Piling causes a significant amount of noise and vibration, which can cause temporary or permanent hearing impairment in marine species, including fish, cetaceans and/or pinnipeds. Guidance developed by the United States National Marine Fisheries Services[57] provides underwater noise thresholds for peak sound pressure levels and weighted cumulative sound exposure levels. It discusses temporary threshold shifts (TTS), permanent threshold shifts (PTS) and onset thresholds for different groups of cetaceans (e.g., low-frequency, mid-frequency and high-frequency cetaceans).

Breaching such thresholds can be a particular issue if piling occurs near or at known habitats of marine animals, but particularly for cetaceans and pinnipeds species. Unmitigated underwater noise from piling can travel long distances at levels above the TTS or even PTS threshold. This risk is increasingly significant when greater hammer strength is used to install the ever-increasing large foundations for newer and bigger wind turbine generator models[58]. The impacts can be further exacerbated if piling is undertaken during a migration or breeding period, or in locations inhabited by protected species.

Dredging works and vessel movement also generate noise at levels and frequencies that depend on their nature, size, and speed. While noise from these sources is expected to have less impact than piling activities, it tends to be continuous, and the impact may be significant if they occur simultaneously.

The noise and vibration caused offshore wind turbines can have ongoing impacts on marine biodiversity. There is a risk that the behaviour and physiology of animals and fish will be impacted. The abilities of many marine species to use sound and vibrations to communicate, avoid predators and detect prey may be impaired.

***Air quality***

Offshore (and onshore) wind farms generally have minimal impacts on air quality as they do not produce significant emissions of pollutants during their operation. Air quality impacts are limited to the construction phase where there is a risk of dust from shore-based vehicular transport. With the limited scope of onshore components of an offshore wind farm, these air quality impacts are typically unlikely to be significant (except where new access roads and transmission lines are required).

Vehicular emissions from both onshore and offshore construction vessels and equipment have the potential to affect local air quality temporarily during construction.

***Water quality***

Offshore wind farms have the potential to affect marine water quality due to:

- Disturbance of the seabed for the installation of foundations and laying of sub-surface cables;
- Dredging works (including offsite dumping of dredged materials) to prepare an offshore area for foundations and vessel movements;
- Suspension of seabed sediment due to certain foundation construction methods, such as suction caisson (an inverted bucket that is embedded in the marine sediment).

These activities can all cause the temporary suspension of seabed sediment resulting in the development of a sediment plume. Due to ocean currents and flows, these sediments can become suspended, transported, and deposited to distant areas, and cause impacts such as:

[57] NOAA (2018)
[58] Bellman *et al*. (2020)

- Degradation of localized marine water quality due to an increase in total suspended solids (TSS) and decreased dissolved oxygen;
- Deposition of sediment and changes to available light for sensitive ecological receptors and areas such as corals, seagrass and coastal habitats (e.g., wetlands).

Such impacts can have both direct and indirect consequences for marine life and ecosystems.

The release of pollutants such as fuels and oils from vessels involved in construction and maintenance can also have a negative impact on sea water quality.

***Waste***

As with onshore wind turbines, offshore wind farm developments generate waste during repowering and during decommissioning. This will be particularly true for turbine blades that come out of service, that will need to be transported to shore for landfilling or recycling.

***Seabed erosion***

The foundations of offshore wind farms can cause seabed scouring[59] due to a local increase in currents and wave motions which can stir up and suspend seabed particles and transport them away from the structure, creating a pit around the structure.

Apart from affecting the geotechnical stability of the foundations of wind turbine generators (in particular, for monopiles), scouring also removes existing marine habitat and prevents new habitat creation.

***Visual and aesthetic impacts***

Depending on its location, a wind farm can alter the character of the natural seascape and visual setting. It may alter how local communities and visitors appreciate the seascape, especially if it is visible from or located near residential areas or tourism sites. Visual impacts associated with both onshore and offshore wind energy projects typically concern the installed and operational turbines themselves (e.g., colour, height, and the number of turbines)[60].

Key factors that determine perceptions of wind farms depend on the proximity of turbines to the viewer and the viewing angles of wind turbines. Seascape visual impacts are largely associated with the siting and layout of wind turbines and related infrastructures, such as meteorological towers, onshore access, and transmission line access tracks (if required), and substations[61].

Tourism activities may also be negatively affected through restrictions on access to public beaches, swimming areas and coastal recreational areas due to the construction of cable landing points, onshore substations, and transmission lines and easements. Careful design can often be implemented to minimize these effects.

***Marine and ecosystem restoration***

Currently, there is no single standard for the decommissioning and marine restoration of offshore wind farms. Regulatory standards, guidelines and best practices for offshore wind farm decommissioning are based on existing standards from the maritime conventions and other industries such as oil and gas. Project plans for decommissioning have vague procedures[62]. The unique characteristics of individual sites requires exclusive optimal solutions for each project. The basic components that need

[59] van der Tempel *et al.* (2004)
[60] Wind Energy. Offshore Impacts (wind-energy-the-facts.org)
[61] IFC (2015)
[62] Topham and McMillan (2016)

to be removed consist of: wind turbines, foundations and transition pieces, sub-sea cables (export and inter-array), meteorological masts, offshore substations and onshore elements as well as any existing scour material. It is important to know what will be done with each of these components before the operations start: if they can be re-used or recycled as a first option, or disposed as final option.

The ecological impact of removing offshore structures at the end of life is unknown and is currently not investigated nor predicted in EIAs[63].

The lifetime of an offshore wind farm is expected to be 20–25 years. By 2021, only seven offshore wind farms had been decommissioned and only a few countries have experience of executing decommissioning projects[64].

Marine spatial planning considers how existing windfarm structures can be enhanced to have a conservation benefits, and how new developments could provide opportunities for such enhancement alongside site selection. There is evidence to suggest the presence of windfarms, especially offshore, could in some cases be environmentally beneficial for certain species. e.g. providing structures/surfaces for the development of artificial reefs for marine life and potential habitat species such as oysters and mussels. Thus, leaving offshore wind farm structures in place once such reefs have developed is an issue for consideration.

Post decommissioning, there will be a need for ongoing monitoring and management of the decommissioned offshore wind site.

### 6.5.3 Key socio-economic Issues and impacts for offshore wind power

#### *Employment and labour conditions*

As with onshore wind farms, offshore projects also provide employment opportunities, especially during the construction phase when significant workforces are required. Such opportunities during construction are increasing but are decreasing during operation. A study of offshore wind in Denmark found that, from 2010 to 2022, the permanent labour requirements for offshore wind farms reduced from 19.0 full-time equivalent (FTE) staff per MW installed to 7.5 FTE MW installed[65].

With the increase in construction job opportunities, there is a need for employers to manage the associated occupational health and safety (OHS) risks. These are addressed in the discussion of onshore wind energy employment and labour. There are additional risks when working on offshore wind farms—working over water and transport to offshore locations by helicopter or supply vessel.

#### *Local economy and livelihoods*

Offshore wind farms affect fishing and other aquatic-based or reliant livelihoods. The presence of offshore wind farms may limit the income of fisherfolk - either directly by prohibiting access around the equipment, or indirectly by temporarily restricting access to fishing areas (e.g., if fish populations are reduced due to the impacts of a wind farm) (Box **6.6:**6.6). These impacts of offshore wind farms (e.g., creation of artificial reefs, energy landscape impacts) can occur during different project phases (Table 6.4). Offshore wind farms can also have an impact on fisherfolk’s costs (e.g., when detours must be made to get fuel).

[63] Hall *et al*. (2020)
[64] Adedipe and Shafiee (2021)
[65] Danish Shipping, Wind Denmark and Danish Energy (2020)

**Box 6.6: Effect of offshore wind farms on fish yields and livelihoods**

Offshore wind farms can affect fish, ultimately reducing fishing yields. This can have a knock-on effect on fishmongers and other jobs reliant on the fish industry. Reduced catches have direct impacts on food supply and can reduce the income security and well-being of fisherfolk households and have negative indirect economic impacts on the local community[66].

There is also the potential for offshore wind farms to displace fishing effort. This is a major issue that SEA can consider, particularly with regard to the identification and development of leasing zones for fishing and making leases available for offshore wind development.

**Table 6.4: Effects of offshore wind turbines on fisheries**
*Source: Gill et al. (2020)*

| | Construction | Operation | Decommissioning |
|---|---|---|---|
| Artificial reef effect | | X | (X) |
| Fisheries exclusion effect | X | X | (X) |
| Fisheries displacement effect | X | X | (X) |
| Energy landscape effects* | X | X | X |

*Energy landscape includes the sensory and physical energy environment
Brackets represent potential effects

### *Health and safety*

- An offshore wind farm can cause negative impacts on community health and safety, particularly when located in an area where there is a high density of shipping movements, fishing vessels and recreational craft use[67].
- Noise and shadow flicker from offshore wind turbines tends to be limited as they are usually installed far from the coastal communities[68].
- Much of the discussion of health and safety issues related to onshore wind farms discussed earlier is applicable to offshore wind farms.

### *Gender and vulnerability*

A recent study found that ethnic minorities and women were underrepresented in the offshore wind farm workforce in the Yorkshire and Humber region of the UK (Box 6.7). A similar situation is likely to be found in other countries where the offshore wind industry is newer.

There are a range of opportunities for local stakeholders (e.g., local governments, community cooperatives, and affected minority groups) to derive benefits from offshore wind projects through skill development and benefit-sharing models[69].

[66] Bergström *et al*. (2014)
[67] Offshore renewable energy installations: impact on shipping - GOV.UK (www.gov.uk)
[68] Offshore Impacts (wind-energy-the-facts.org)
[69] IFC (2019b)

**Box 6.7: Jobs in the offshore wind industry in the Yorkshire and Humber Region, United Kingdom**

A recent study predicted that the number of jobs available in the Yorkshire and Humber region would increase from 1,500 in 2017 to 9,200 by 2032. At the same time, just 4% of the current workforce is from a Black, Asian, and minority background compared to 8.5% of the available employee pool. Females made up 22% of the workforce in 2017. The prevalence of men employed in the industry makes it important to assess the potential for gender-based violence and risky behaviour resulting from an influx of predominantly male construction workers. The study recommended females and those from Black, Asian, and minority ethnic backgrounds should be encouraged into the industry.

*Source: Murphy (2018)*

***Marine navigation***

The presence of offshore wind farms can present difficulties for marine navigation. They can interrupt marine traffic, routes and activities located near ports, harbours, known shipping lanes, mooring locations, and commercial and recreational fishing grounds. If not properly managed, this can lead to marine injuries and casualties including death or loss of property—either at sea or among the onshore population[70]. Wind farm installations can also be at risk of collisions with boats (Box6.8). The disruption of navigation routes can cause economic loss due to the extra time needed for boats and cargo ships to access ports and can also delay supply chains of both non-consumable and consumable goods.

**Box 6.8: Cargo ship collides with Hollandse Kust Zuid Wind Farm, The Netherlands**

The Hollandse Kust Zuid wind farm consists of two sites, which are located between 18 and 36km off the Dutch coast, between The Hague and Zandvoort.

On 31 January 2022, a cargo ship and an oil tanker collided, resulting in one of them being left rudderless and later striking a platform foundation of the Hollandse Kust Zuid wind farm – two sites under construction off the Dutch coast. All personnel aboard the cargo ship were evacuated by helicopter. Reports of the accident made no mention of staff working on the foundation at the time of the collision and damage was still being assessed.

*Source:*
*www.4coffshore.com/news/vessel-collides-with-hollandse-kust-zuid-foundation-nid24925.htm*

***Aviation and telecommunications***

Offshore wind farms can present safety risks for low-flying aircraft, requiring the rerouting of flight paths. They can also cause signal distortion and interfere with aviation and ship radar as well as cause electromagnetic interference to telecommunications and broadcasting systems (Box6.9).

***Public services and infrastructure***

As with onshore wind farm projects, offshore wind companies may contribute to improving local public services and infrastructure. The construction, operation and maintenance (O&M) processes for offshore wind farms may require upgrades to public infrastructure such as roads and ports, which can generally be a net positive impact for those locations. Offshore wind farms can also contribute to

[70] Maritime and Coastguard Agency (2012)

increased revenue for local governments through taxes on offshore wind farm projects. Onshore supply bases will also be required to support offshore construction and operation of wind farms.

**Box 6.9: United Kingdom's Maritime and Coastguard Agency and offshore wind farms**

According to the United Kingdom's (UK) Maritime and Coastguard Agency, mariners and organizations require consistent and effective radio communications systems. If they are within close range of an offshore wind farm, they should be able to rely on marine navigation systems as much as if they were in the open sea. However, these systems may be affected by wind turbines. In the UK, to mitigate these risks, the government requires using temporary safety zones during construction, major maintenance, and decommissioning. The agency's website indicates that permanent safety zones are not expected to be established around entire wind farm groups, though for single installations this may be considered.

*Source: www.gov.uk/government/organisations/maritime-and-coastguard-agency*

***Human rights***

Typically, as for onshore wind farms, wind turbines (generators, towers, blades, nacelles, gearbox) require metals and minerals that mining companies may extract from countries where human rights are poorly upheld. Wind farm companies need to address this issue through due diligence, examining the activities of their wind turbine and blade suppliers, and imposing requirements on suppliers to eliminate and remedy adverse human rights impacts